DATING THE PAST

An Introduction to Geochronology

by

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PREFACE

This book has grown from courses of lectures delivered at the Institute of Archaeology of the University of London, and from a number of occasional lectures given at several colleges and to learned societies. It represents a first, and necessarily inadequate, attempt to combine the very diverse methods of dating the past into one discipline, *geochronology.*

Geochronology is a very young branch of science, which draws its methods from geology, botany, zoology, and physics. Its chief objective, the development of time-scales in years which extend back into the distant past beyond the historical calendar, binds the different methods together, but since they have been developed by specialists in their respective fields, the common aim is frequently overlooked, and cross-checking of results obtained by different means is often sadly neglected.

The chief field of application of geochronology is in prehistoric archaeology and human palaeontology. The evolution of man, both from the anthropological and the cultural points of view cannot be understood properly, unless the time element is introduced. The major portion of this book, therefore, has been written with special regard to archaeology.

The second field of application of geochronology, closely tied to the first by the problem of the evolution of man, is that of biological evolution in relation to time. In order to draw attention to this matter, a separate chapter has been devoted to it.

There are, of course, many other fields of application of geochronology, in geology and geophysics, some of which are outlined, in a sketchy manner, in Chapter XI.

It is clear that the great diversity of the material dealt with in this book renders an even and impartial treatment impossible. The author himself has worked chiefly on the climatic phases of the Pleistocene and the chronology of the Palaeolithic, and the chapters describing and discussing this matter naturally contain a fair amount of original work, while the other chapters (except that on biological evolution) are mainly the result of careful compilation. No doubt errors will have crept in in some places, though I hope I have always been cautious in trusting to good authorities. I shall be grateful for any mistakes pointed out to me.

In view of the newness of the subject it has been necessary to describe in some detail part of the actual evidence. Though this might render reading less easy, such disadvantage is, I believe, far outweighed by the increased usefulness of the book as a work of reference.

For the same reason, ample bibliographies have been provided, comprising in all about 650 books and papers written in 15 different languages. The bibliographies cannot be complete, especially since great difficulties have been encountered in the looking-up, checking, and completing of the references under the present war-time conditions. This must also have caused me to neglect or omit many an important publication. I tender my apologies to authors of such works and wish to emphasize that omission does not mean that their work has been regarded as unimportant. Again, I should be grateful if faults of this kind be pointed out to me.

The general reader who is not interested in the special evidence given in some of the chapters will nevertheless be able to profit from the book by concentrating on the numerous general sections and summaries. The plates have been prepared chiefly for the benefit of the reader who is little acquainted with the kind of evidence used in dating, and elaborate explanations of the figures have been provided which, it is hoped, will make the photographs intelligible.

The chronological results have been summarized in numerous tables, a list of which is given on page xvii.

In the course of the preparation of this book, which has taken the best part of seven years, I have received invaluable advice and assistance from many quarters, friends, and colleagues, as well as institutions, while travelling, carrying out field work and preparing the manuscript. It is impossible to thank them each individually, which does not render my gratitude less profound. Only some of the most conspicuous helpers can be mentioned here.

First and foremost I owe a great debt to those who read the whole or part of the manuscript, above all to my friend, Mr. Day Kimball, who undertook this labour twice over and with whom I have discussed every major problem involved. His invaluable constructive criticism, enjoyed at all stages in the preparation of the book, has substantially contributed to the improvement of its form and contents. The whole or part of the manuscript was further read by, and many valuable

suggestions received from, Messrs. P. G. H. Boswell, V. Gordon Childe, W. N. Edwards, A. Holmes, E. V. Rieu, B. P. Uvarov, and Misses D. M. A. Bate, M. Eates, and D. A. E. Garrod. If this book has any merits at all, they are no doubt largely due to the kind assistance these friends and colleagues have given me in the most unselfish manner.

An enormous amount of information was willingly supplied and guidance provided on travels, often with a considerable sacrifice of valuable time; material for figures was secured and technical help given in the preparation of the book, by the following ladies and gentleman: Messrs. A. L. Armstrong (Warrington), E. Bailey (London), S. Barral (Monaco), A. C. Blanc and G. A. Blanc (Viareggio), L. C. W. Bonacina (London), Mrs. A. Bowler-Kelley (Paris), H. Breuil (formerly Paris, at present Johannesburg, South Africa), J. P. T. Burchell (London), Miles C. Burkitt (Cambridge), J. G. D. Clark (Cambridge), S. Corbet (London), L. Davidaschvili (Moscow), Miss T. Edinger, (Harvard), S. R. K. Glanville (London), H. Godwin (Cambridge), E. F. Guiton (St. Hélier), M. A. C. Hinton (London), A. T. Hopwood (London), S. A. Huzayyin (formerly Alexandria, now London), Miss M. Johnston (Kew Gardens), Harper Kelley (Paris), A. S. Kennard (London), W. B. R. King (Cambridge), L. Knopp (Rybnik), M. Labande (Monaco), A. C. Lane (Harvard), F. Lorenzi (Grimaldi), C. van Riet Lowe (Johannesburg), G. Mirčink (Moscow), the late J. Reid Moir (Ipswich), S. Morris (London), A. E. Mourant (St. Hélier), the late J. R. Norman (London), K. P. Oakley (London), C. D. Ovey (London), W. C. Pei (Peking), A. S. Romer (Harvard), P. E. Stasi (Castro Marina), W. Szafer (Krakow), G. Talbot (London), D. V. Tchernavin (London), H. Dighton Thomas (London), A. du Toit (Cape Town), Miss Z. Waloff (London), D. M. S. Watson (London), E. J. Wayland (Gaberones, Bechuanaland), F. Weidenreich (New York), R. E. M. Wheeler (formerly London, now New Delhi), B. Zaborski (Krakow), B. F. Zemlyakoff (Leningrad), Mrs. I. H. Zeuner (Kew Gardens).

I would like to record my sincere gratitude to all of them, as well as to the many unnamed friends who have helped me in the same manner.

Finally, my grateful thanks are due to the following institutions who have supported me in various ways, chiefly in connexion with expeditions: The Leverhulme Trust of the London Museum, the Institute of Archaeology of the University of

London, the Société Jersiaise, St. Hélier, Jersey, and to the Department of Geology of the British Museum (Natural History) for its hospitality, since the Institute of Archaeology had to be closed down as a result of the war.

The Brazilian Embassy, the British Museum (Natural History), the British Standards Corporation, London, the Ray Society, the Royal Entomological Society of London, the Prehistoric Society, the *Geological Magazine*, and Messrs. Thomas Nelson & Sons, Ltd., have kindly permitted me to reproduce certain figures.

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INTRODUCTION

A thousand years in Thy sight are but as yesterday when it is past, and as a watch in the night.—PSALM 90, v. 4.

In these days of war people are apt to say that the face of the earth is changing more rapidly than ever. If one confines such consideration to one's own restricted world, it is certainly true to some extent, though less so if one applies it to nations and countries. History demonstrates how often periods of disturbance have swept over continents and how little permanent the effects of such storms often have proved to be.

A storm might determine the weather of a day, but not the climate of a region. This comparison is well applicable to the stages of culture and civilization through which the peoples of the earth have passed. There were plenty of stormy periods, yet the Graeco-Roman culture, evolved more than 2,500 years ago, still provides the ground on which we build to-day. The Chinese culture is even older and still flourishes.

Mankind's cultural changes have, indeed, been comparatively slow and have to be measured in hundreds and thousands of years, and in searching for the roots of the present-day cultures one invariably has to go back to prehistoric times.

History has the advantage of written records and of calendars which provide more or less reliable *dates* and therefore allow of estimating or determining the duration of periods of evolution.

For Prehistory, no calendars are available. Up to not many years ago, the time-scales suggested for the evolution of early man and his cultures were pure guesses, not to say imagination. From a scientific point of view they were worthless. Yet nobody can claim that the time-problem in the evolution of man is of little significance. The study of the remains of fossil man has revealed that the characters of the body did not remain constant since man appeared on the earth, and the study of implements and cultural remains of early man shows that intelligence and mentality were subject to changes, that one group of man influenced the other and that new cultural units were developed on the ground of mutual contact between different groups.

It is of the utmost importance to learn about the time required for these processes. Modern man, indeed, experiments in these matters on a large scale, though rather unsystematically. The most remarkable case is that of the United States of America, where an increasingly homogeneous population is evolving from an extremely heterogeneous stock. But a few hundred years have sufficed to develop a distinct American culture, and there are signs

that a physically definable American race might ensue. We cannot tell yet how far these processes will go, but it is obvious that time is bound to play an important part.

The past could teach us much in respect of the rate of the evolution of cultures and the consolidation of races, provided sufficiently reliable *time-scales* were available. It is only in recent years that science has begun to fill this gap in our knowledge. Time-scales *are* now available for the entire period of man's established presence on the earth. One main purpose of the chapters which follow is to explain the methods employed in establishing time-scales for the prehistory of man.

Man is but too inclined to regard himself as the main figure on the earth's face. The real face of the earth is its landscape, determined by physiographical elements like elevation, relation to rivers, vegetation, animal life and, dominating all, by the climate. It is the *environment* of man. He depends on it in every respect, as regards food, clothing, housing; in short the mode of life of a people is conditioned by its environment. Beyond this—it is almost a commonplace to mention it—environment exerts an immense influence on man's mentality.

Just as man has himself changed in the course of time, so has his environment, the changes being due to geological factors. The greater portion of Prehistory falls within the Ice Age or Pleistocene, a period from which the earth has only just emerged. During this time, ice-caps were repeatedly formed in the polar and temperate regions of the earth and the climate everywhere was profoundly affected. Several such periods of glaciation alternated with periods of a 'normal' climate resembling that of the present day. The man of the Old Stone Age adapted himself and his culture to these climatic fluctuations, and evidence shows that they were a first-rate stimulant for migrations as well as for the advance of civilization and culture.

Again the problem arises as to how much time was required to bring about such and other changes in the environment. We now know that tens of thousands of years have to be used as a time-unit in the chronology of the Ice Age. Several of the chapters which follow will describe how a time-scale has been arrived at, dating the environmental changes which occurred during the Ice Age.

Man is not known to have existed for any great length of time before the Ice Age began, but geological and palaeontological research have revealed that man's period on earth is not more than the brief final episode in the long story of life on earth. Though the beginnings of life are as yet obscure, it is evident from the records preserved in the oldest known geological deposits and in those formed subsequently, that an evolution took place, successively more highly organized types of animals and plants appearing and

replacing certain others which became extinct. In many instances it has been established definitely that a certain species, such as a shell or a mammal, changed its characters and gradually became transformed into another. These changes obviously required considerable time. For the study of the processes of evolution as well as for our general conception of what life is, it would be extremely important to know, if only approximately, how much time in years was required for such changes.

In recent years the study of heredity has been greatly advanced by biologists, and much of the mechanism governing the changes in hereditary characters has been detected. The problem has arisen whether changes in the environment, such as climatic ones, affect and modify hereditary characters. The evidence contained in the geological deposits very strongly suggests that the species of life do respond to environmental changes. The time required for such response to become effective cannot be determined by means of experiments in the biological laboratory; but the geologist, provided he can establish a reliable time-scale in years for the phases of the earth's history, will be able to supply examples for the time-rate of evolution. It is obvious that such knowledge is almost basic for the understanding of the processes of life, including man. For this reason, the last three chapters of this book are dedicated to the time-scales of the distant geological past and their significance for the evolution of life.

Although modern science has greatly stimulated research to 'date the past', the problem as such is very old and has always fascinated mankind.

From the earliest phases of history onwards we meet with a desire to date the remote past, and estimates have been put forward for the age of the earth and of mankind in particular. Several calendars are based on assumed dates for the creation of the earth or for the appearance of man. The best known of these is the Jewish calendar which also is one of the shortest; it counts 5,700 years since the creation, though attempts have been made to correct this date. According to the version of the Bible used and to the system of calculation applied, results for the date of creation vary from 3616 to 6984 B.C. The ancient Greeks appear to have assumed a somewhat greater age, as Plato mentions that the Elysian Atalantis became submerged about 9,000 years before his time and that the Egyptian priests were acquainted with this figure. The Persians admitted 12,000 years for the age of mankind, and the Egyptian priests counted 341 generations, or about 10,000 years, between Menes and Sethon.

Further east, however, long-range chronologies were in greater favour. Thus the Chaldeans of Mesopotamia allowed (in their time) 473,000 years for the age of mankind, whilst they said the creation

of the earth took place more than two million years ago. The Chinese, too, estimated the age of the world at several hundred thousand years. The longest chronology is that of the Hindu. It comprises four Great ages: namely the Golden, the Silver, the Brazen and the Iron Age, each lasting about 4·3 million years. The Iron Age is said to have begun in 3101 B.C., so that about 13 million years would have elapsed since the beginning of the Golden Age.

All these chronologies are based on tradition and myth, and therefore are of no scientific value. It is remarkable that most of them make little or no distinction between the age of the earth and the age of mankind. Modern research has shown that the earth had existed for an almost incomprehensibly long time before man appeared on it. Curiously enough the Chaldeans made that distinction, and their estimate for the age of man is not so far from the correct figure. Yet, none of the early chronologers ever dared to put forward an age of the earth approximating the figure of 2,000 million years now accepted by science as a minimum.

Scientific research aiming at the establishment of a chronology in years for the long space of time before the records of history provide us with definite dates, has only just begun. Various methods have had to be applied in order to obtain data in years for those times which are called "pre"-historic. These methods are either biological or, predominantly, geological.

As the historical calendar, so is the geological based on rhythmic occurrences (cycles) of an astronomical character (day = rotation; season = obliquity; year = orbit). Only for very remote periods physical cycles have to be employed, but it is by no means unthinkable that an astronomical calendar be established in future, extending back to the earliest periods.

The most elementary cycle is the year. The sunspot period of 11·4 years is another cycle of short duration. Among the longer ones are those of the precession of the equinoxes (21,000 years), the obliquity of the ecliptic (40,000 years) and the excentricity of the earth's orbit (92,000 years). The longest cycles, or rather periods, employed, are those of the decomposition of radioactive minerals some of which are counted in hundred thousands and millions of years.

There are four geochronological methods, each of which is capable of covering not more than a limited range of time. Fortunately one method can be applied successfully where the other fails, so that the absolute time-scales so far obtained cover the postglacial prehistory of man in fair detail (measuring in centuries), the Old Stone Age (roughly equal to the Pleistocene or Ice Age) in tens of thousands of years, and the earlier geological periods in a more general way (measuring in millions of years). Thus, a reasonable

idea is conveyed of the time required for the development of the physical features of the earth, for the evolution of life, and for the evolution of man and his successive cultural phases.

The methods, which are described in this book are the following:

(1) *Tree-ring analysis*, relying on the cycles of the year and the sunspots, covering historic and prehistoric phases in North America, and extending over the last 3,000 years: Chapter I.

(2) *Varved clay analysis*, relying on the cycles of the year, the sunspots, and the precession of the equinoxes, covering the time from the end of the Palaeolithic to the Iron Age, and extending over the last 15,000 years: Chapters II to IV.

(3) *Solar radiation method*, relying on the cycles of the precession, obliquity and eccentricity, covering the Palaeolithic and the Ice Age, and extending over about 1 million years: Chapters V to IX.

(4) *Radioactivity method*, relying on the periods of decomposition of radioactive minerals, covering all geological formations previous to the appearance of man, and extending over about 1,500 million years: Chapters X to XII.

All these studies aiming at the establishment of absolute time-scales for the past are comprised by the term *Geochronology*. Geochronology literally means time-counting in relation to the earth and implies that counting in years is aimed at, as distinct from stratigraphy which is concerned with the relative ages only. The term was introduced by H. S. Williams [1] in 1893 to designate studies in which the geological time-scale (in absolute time) is applied to the evolution of the earth and its inhabitants. Charles Schuchert [2] interpreted it as the age of the earth on the basis of sediments and life. Both these definitions emphasize the close relationship of geochronology and stratigraphy, and in fact all the methods described in this book rely upon 'strata' of some sort. This applies to the counting of the annual growth-rings of trees as it does to the lava-beds investigated by the radioactivity method, which have to be defined in their position relative to sediments before the figure of age can be usefully interpreted. The term 'geochronology', therefore, is employed here in a comprehensive sense, and not restricted to any particular method; such as, for instance, de Geer's chronology based on the annual layers produced by the meltwater of glaciers.

Geochronology may thus be defined as the science of dating in terms of years those periods of the past to which the human historical calendar does not apply. It covers human prehistory as well as the whole of the geological past.

[1] Williams, H. S., 1893. 'The Elements of the Geological Time-scale.'—*J. Geol.*, Chicago, 1, pp. 283–95.

[2] Schuchert, C., 1931. 'Geochronology, or the Age of the Earth on the Basis of Sediments and Life.'—*Bull. Nat. Res. Council*, Washington, 80, pp. 10–64.

PART I

DATING EARLY HISTORY AND LATE PREHISTORY, ESPECIALLY IN NORTH AMERICA

(*Back to about* 1000 B.C.)

CHAPTER I

DENDROCHRONOLOGY, OR TREE-RING ANALYSIS

A. PRINCIPLES OF TREE-RING ANALYSIS

History and principles. The first of the chronological methods to be described is generally called *tree-ring analysis*, and the branch of science dealing with it, *dendrochronology*. As a scientific method, it was conceived by Douglass in 1901, though the idea of using tree-rings for the dating of archaeological sites is old. As early as in 1811 De Witt Clinton, when examining the earthworks near Canadaigua, in the State of New York, counted the rings in the trees growing upon them and estimated that they were one thousand years old, and hence the work not of Europeans or present-day Indians, but of a prehistoric people.

Modern dendrochronology is, of course, a matter very different from this early attempt. It has established a sort of calendar for the last two or three thousand years. Its results fall entirely within the historical periods of Europe and Asia; but in North America where intelligible written records are not known before the end of the fifteenth century, this method leads back right into prehistoric times. It has been most successfully applied to the dating of prehistoric villages in the south-western United States.

Tree-ring analysis is based on a well-known structural feature of wood, namely the annual growth-rings. These are shown by trees growing in regions with regular seasonal changes of climate, i.e. regions where either a dry and a wet season, or a mild and a frosty season, alternate. As a rule trees produce one ring every year. The annual ring is formed by the *cambium* which lies between the old wood and the bark. In spring or, more generally, when the growing season begins, sets of large, thinly-walled cells are added to the wood. As the season advances towards the end of the summer or of the wet season, the cells added to the wood become increasingly smaller and more thickly-walled, until the production of cells ceases entirely. In the following year this process is repeated, and a distinct demarcation line is thus formed between the summer wood of the previous year with its small cells and the spring wood of the following year with its large cells (pl. I, fig. A).

The growth-rings of each individual tree are not of the same thickness throughout. They vary for two reasons :—

(1) The thickness of the growth-rings varies with the age, the rings becoming narrower with the increasing age of the tree (pl. I, fig. B). The central rings, therefore, are always wider than the peripheric ones.

(2) Superimposed on this normal variation in size of the rings is a variation caused by the inequalities of the climate from year to year (fig. 1). In years with unfavourable weather, that is, mainly in years with abnormal periods of drought, abnormally narrow rings are formed. On the other hand exceptionally broad rings will be produced in years with abundant supply of water and food. A curve reproducing the variation in a series of rings observed in the cross-

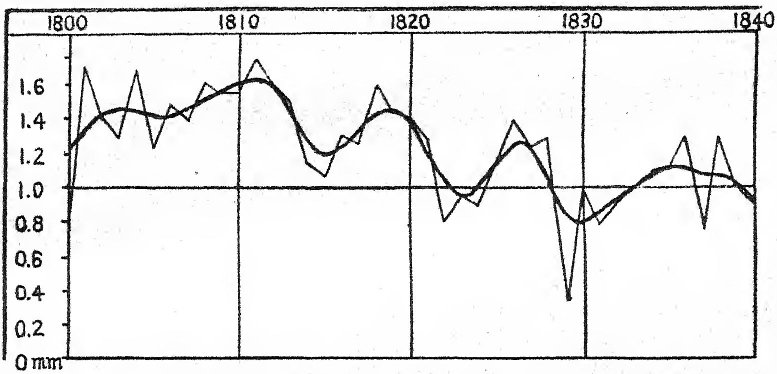


FIG. 1.—Tree-ring graph as used by Antevs and others. The thickness of each ring is given in millimetres, and a broken curve is drawn. The smoothed curve is obtained from the broken one by an averaging process described by Antevs (1938).—After Antevs (1938).

section of a tree, therefore, reproduces to some extent the variation of the local climate. It is on this fact that the applicability of tree-ring analysis to dating depends, since most trees of one area tend to exhibit similar variations in their ring-records.

The properties of the growth-rings enable one to correlate with one another growth-rings of different trees of the same district (fig. 3) and to count backwards in years, correlating the inner rings of young trees with the outer rings of older trees. The method can be applied not only to trees of a certain wooded area but also to the timber derived from it and used by man in the construction of historic or prehistoric dwellings. In this way it has been possible to assign dates in years to a large number of prehistoric sites, chiefly in North America.

Dr. Douglass and his collaborators, in the course of their research, have worked out in great detail the method of tree-ring analysis.

They have standardized it and studied the ways of overcoming certain difficulties which will be discussed below. Recently, W. S. Glock (1937) has summarized the fundamentals and the technique in his *Principles and Methods of Tree-ring Analysis*, and further interesting information may be obtained from the Tree-ring Bulletin published four times annually at Flagstaff, Arizona.

Collecting specimens. Samples have to be collected with care. Species of the plant, date of collecting, diameter, height of the sample above the root, topography of the locality, situation in respect to drainage lines, types of soil, bed rock and surrounding vegetation have to be noted. The most perfect type of sample is, of course, a slice across the whole tree as near root-level as possible, though root-buttresses have to be avoided. In view of the bulky nature of this kind of sample it is often necessary to content oneself with a rectangular radial cut across the section, including the centre. V-shaped cuts are still smaller and lighter than rectangular blocks. In recent years special borers have been introduced which enable the worker to extract from the tree long and thin cores which are easily transported.

Samples should not be taken from trees the roots of which have permanent access to water, since they are more or less independent of the fluctuations of the climate and, therefore, do not exhibit sensitive rings (see p. 9).

Ring examination. In the laboratory the specimens have to be prepared for examination by smoothing the surface with a razor, or by polishing. Liquids may be used to render the rings more visible. The counting and reading of the ring sequence is carried out along a radius on which, for convenience, every tenth ring may be marked with a hole pricked into it with a pin. According to the method of Dr. Douglass, the variation in thickness of the rings is then plotted on co-ordinate paper (fig. 2). Rings of ordinary thickness are not marked on the plot but merely counted, whilst rings which are unusually thin as compared with their immediate neighbours, are noted by means of a vertical line which is the longer the thinner the ring is compared with its neighbours. Exceptionally broad rings are marked on the plot with a letter ' B ', ' BB ', etc., according to their relative widths.

The resulting plot is called a ' skeleton plot '. It has the advantage of being independent of the decreasing average thickness of the rings with the increasing age of the tree. Moreover, it can be constructed without carrying out exact measurements and it therefore is eminently suitable for field-work. Skeleton plots clearly show the occurrence and position of rings with unusual features, on which correlation work is based.

For many purposes graphs giving the thickness of each ring in millimetres are to be preferred. As an instance one of Dr. Antevs's

plots is reproduced here (fig. 1). This kind is reminiscent of those used in the analysis of varved clays (see page 22).

In the process of counting and reading a specimen certain difficulties occur. There are not only sequences of rings of approximately equal thickness (called *complacent rings*) and ring-sequences in which the width varies (called *sensitive rings*) but double rings also are sometimes observed and evidence may be found for the partial or total absence of others.

Difficult rings. Occasionally, duplication of a ring may be observed which either extends round the entire circle or is restricted to a portion of it. It may be due to two really independent rings lying close together, each of them representing one year. On the other hand an actual duplication may have taken place, the growth

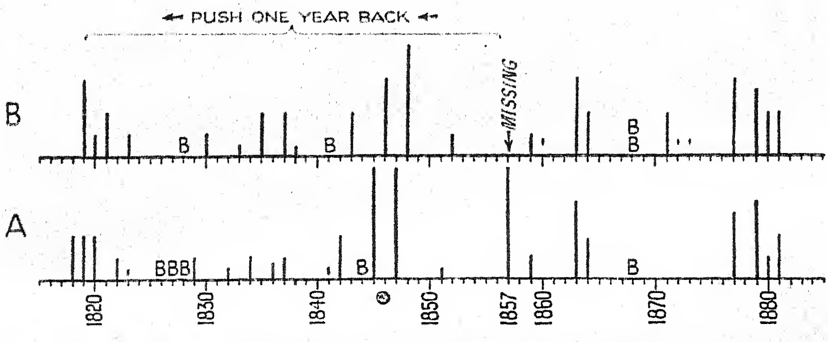


FIG. 2.—Tree-ring plots as used by Douglass. Normal rings are not marked but merely counted. A vertical line indicates a narrow ring; the longer the line, the narrower the ring. 'B' indicates an unusually broad ring.

A.—Rings of an Arizona Pine, between A.D. 1815 and 1885.

B.—Rings of a tree from the same locality, with ring for A.D. 1857 missing. In specimen (*A*) this year is represented by a very narrow ring.

Both diagrams based on Glock (1937, fig. 10).

having stopped for a short time during the ordinary growing season and having been resumed subsequently. It is obvious that such cases have to be cleared up before dating becomes possible, since one year more or less depends on them. Glock, who worked on *Pinus ponderosa*, found a rule which he formulated as follows: 'If a thin band of summer wood lies closely inside a thick band of summer wood, the thin one is part of a double; but if the thin band lies immediately outside the thick band, the thin one is part of a separate annual ring.' This rule helps in many cases, and in others the expert will be able to come to a decision by means of a microscopic study of the cell-structure of the ring under suspicion. If this and a comparison with other specimens from the same locality do not lead to an unambiguous result it is best to discard the specimen.

Sometimes it happens that the ring of a certain year is entirely absent in the specimen under examination (fig. 2). The risk of missing a ring is particularly great if only part of the wood section is available for examination, as often traces are preserved in another

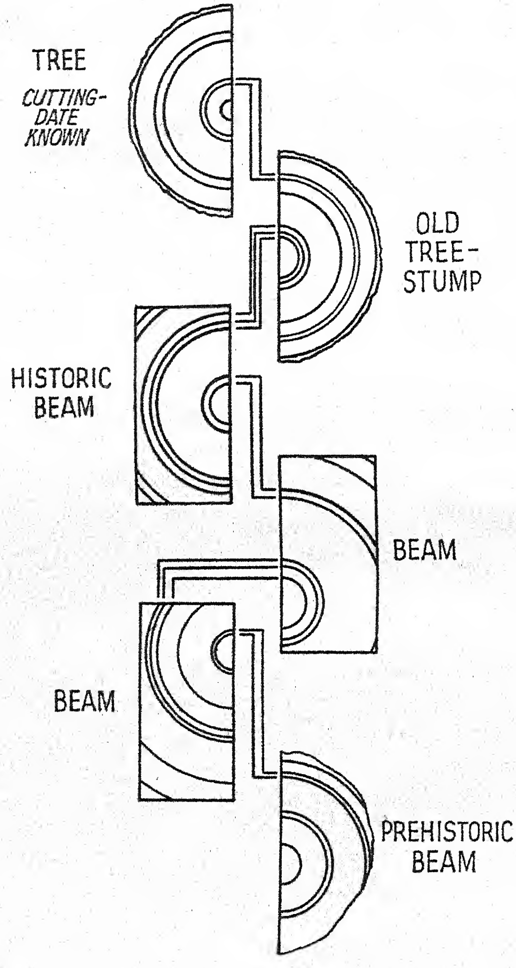


FIG. 3.—Schematic drawings of a series of wood-sections, illustrating cross-dating, and how a chronological sequence is built up connecting prehistoric timber with modern trees.—Based on Glock (1937, fig. 18).

section of the ring-area. For this reason it is invariably preferable to investigate complete slices and to follow each ring round the entire circle. Absence of a ring is, of course, frequently revealed by comparison with another specimen, as shown in fig. 2.

Cross-dating. Having constructed a number of plots of individual trees one proceeds to ' cross-date ' them. This is the term used by dendrochronologists for correlating the ring-series of one tree with that of another. The ring-series of an old tree overlaps to some extent with that of a younger tree, and the arrangement of narrow and wide rings enables one to identify certain sequences of years in the two specimens (fig. 3). Comparison of a large number of specimens helps to eliminate individual aberrations, and in the course of the work there crystallizes from the numerous individual plots a ' standard plot ' which is typical of the region under investigation. If curves of the kind shown in fig. 1 are used, corrections have to be applied in many cases in order to eliminate the decrease in average thickness of the rings with increasing age of the tree (pl. I, fig. B). Methods of correction have been designed by Antevs, Douglass, and Huntington. Occasionally the curves are smoothed out in accordance with certain formulae in order to ease the study of any cycles which may be hidden in the curves (compare fig. 1).

B. DATING OF PREHISTORIC SITES

It is evident that for the purpose of dating not only recently felled trees have to be studied but older specimens also. Such may be procured from wood used as timber in houses or other structures, though it is essential that the provenance of this timber be the same as that of the Recent trees studied. Douglass, working on the prehistoric Indian villages in Arizona, gradually extended his tree-ring scale from modern times to logs and beams in modern Indian villages. In many of these houses beams derived from ancient buildings had been used repeatedly, and a fair amount of early historic and prehistoric specimens were recovered in this way. These provided the required link with the actual prehistoric dwelling sites which thus could be dated in years (see pls. II, A, B ; III, A, B). The earliest tree-rings obtained in this region date from about 1,900 years ago, or almost 1,500 years before the Europeans began the conquest of America. An estimated tree-ring chronology for this long space of time is being published by A. E. Douglass in the Tree-ring Bulletin. Most of the datable Indian villages, however, were built between about A.D. 1000 and the conquest. The scope of tree-ring dating is extending rapidly, and satisfactory dates for the archaeological phases in the south-western United States go back to the fourth century. The following table summarizes the results so far obtained. It is based on a number of publications which have appeared in the Tree-ring Bulletin. As overlaps are bound to occur, the dates have to be regarded as approximate. Those who are interested in more accurate, though local, datings, will find them in the periodical just referred to.

Dates for Indian dwelling-sites.

Dates for archaeological phases in the south-western United States, derived from habitation sites and based on tree-ring countings.

Phase[1]	Approximate years A.D.
Pueblo V	1700–1800
Pueblo IV	1300–1650
Pueblo III	1000–1300 (1350 ?)
Pueblo II	900–1100
Pueblo I	750–950
Basket Maker III	400–750
Basket Maker II	? –400
Basket Maker I	?

Dr. Douglass on the dating of Indian pueblos. This table summarizes the results of Douglass and his collaborators. As regards the actual work it is best to follow his own words as he describes the story of one of his discoveries which enabled him to connect an undated but certainly very early ring-series from timber of prehistoric villages with the dated tree-ring series leading backwards from the present day to the times of the Spanish conquest.[2]

Generations of Hopi Indians had dwelt among the mesas 100 miles north of where the Santa Fé Railroad crosses the Little Colorado River, near Winslow, but one of them, Oraibi, has been regarded as the only present-day Hopi village continuously occupied since a period antedating the advent of the Spaniards in 1540. Many of its logs were cut by stone axes and obviously are very old. Small chips taken off showed whether the rings had the strong marking of pine or fir, the weak lines of cottonwood, or the narrow, erratic lines of juniper. Length also helped in the selection. Pre-Spanish beams are rarely more than eight feet long, Spanish beams are easily twice that and nearly always found in the kivas, or ceremonial chambers. They were salvaged by the Hopis when they destroyed the missions in 1680 and have been in use ever since.

A rounded log in the Antelope Kiva at Oraibi gave the year 1475 as its outermost ring, but there was some wear on the outside, which later became recognized as a regular feature of the oldest logs. This log was cut about 1520. A specimen from Moong Kiva, at Walpi, also appeared to be nearly complete, and its outside rings gave 1490 as its cutting date. Ladder poles were more recent. One ladder showed one pole cut in 1570 and the other in 1720 which reveals a story of breakage and repair.

Naturally Dr. Douglass wanted the oldest log. It was found in a part of Oraibi village which had been abandoned by the Indians in 1906. Difficult of access, in a room of one of the old houses, there

[1] For a revised nomenclature, see Roberts (1939).

[2] The succeeding paragraphs follow closely Dr. Douglass's report in the *Geographic Magazine*, 1929; but the story has been shortened and modified so as to suit the subject-matter of this chapter.

was in the centre an upright post, not more than six inches in diameter, supporting the ceiling. It was partly flattened, and as it was holding up the floor of the room above, no cross-section could be taken, but its longer diameter was bored. The rings of this beam gave a superb series from 1260 to 1344. Allowing for wearing it was probably cut as early as A.D. 1370 and had been in use continuously for well over 500 years.

Having made large collections from Oraibi Dr. Douglass thus found that the earliest cutting date was close to the year 1400, and with one or two exceptions no further pieces were found the inner rings of which began earlier than 1300. The inference seemed obvious: these pueblos (which were abandoned following the revolt of 1680, when the Hopis erected their present villages) were built about 1400. Only in the case of Oraibi has the original site been occupied ever since.

Thus it became clear that the available Hopi beams were not sufficiently old to link definitely the historic sequence with the ring-records obtained before from the early prehistoric sites. A survey was made, therefore, of the area known archaeologically to have been inhabited by the Hopis in pre-Spanish times. The fragments of pottery collected at each important ruin showed a sequence of development, and the relationship between the latter years of the prehistoric and the earlier years of the historic chronologies to the sequence of pottery types was easy to determine.

Kawaiku proved to be a place likely to yield fresh information. The first specimens from here were just pieces of charcoal, but some of them exhibited rings closely resembling those between A.D. 1365 and 1420.

Absolute certainty was finally obtained from a specimen of charcoal as big as a fist, found in an old kiva at Kawaiku. It was soaked in paraffin solution and its rings examined. They gave a perfect and reliable sequence from 1400 to 1468. This established conclusively the correctness of all the other dates which had been obtained of approximately the same period.

Further specimens came to light and extended the sequence back to 1300 and forward to 1495, showing that no new dwellings were erected in this village for a short time before the Spaniards reached the district in 1540. There was ample evidence that Kawaiku was occupied both in the latter years of the prehistoric sequence and the earlier years of the historic chronology.

Excavations at another place, Showlow, at last provided the final link between the two sequences. Among the valuable material found here first place must go to the log taken out just after Mr. Judd and Dr. Douglass arrived. It was found in a horizontal position and resembled an ordinary beam which had been burnt off at the end in the form of a cone. Its outer parts were at once

recognized as belonging to the fourteenth century, rings being traceable nearly to A.D. 1380. The record it gave the investigators after 1300 was absolutely satisfactory, with no question remaining as to the dating. Following its rings inward to the core they saw among other features the record of the 'great drought.' Here were the very small rings that told of the hardships the tree had endured in 1299 and 1295. As the rings were studied further towards the centre, 1288, 1286, 1283, and 1280 each told the same story, found in other beams, of lean years and hard living. Also there were the years 1278, 1276, and 1275, the ring for each corroborating the diary entries other logs had given. Even near the centre the rings of this specimen were clear and easily understood. The one at the very core showed that this charred log began life as a promising upright pine in A.D. 1237, just ten years after the Sixth Crusade moved eastward to compel the Saracens to restore Jerusalem.

The history contained in the beam held the investigators spellbound. They felt that this was the tie that would bind the prehistoric chronology to the historic.

Later that day they gathered under the spluttering old gasoline torch in the village hotel and, by the use of Dr. Douglass's skeleton plots they began to determine whether the historical chronology, now extended back from 1260 to 1237 by beam HH39, might not overlap the prehistoric chronology. As the rings were studied the answer came. The ring that represented the 551st year of the prehistoric chronology matched perfectly with the ring for the year 1251 in beam HH39. This was a great surprise. There was no gap to be bridged as had been assumed; the gap had been closed without knowing it.

The two chronologies had covered an overlapping period. But the rings of the prehistoric series which overlapped the historic at 1260 had been gathered from such small fragments that Dr. Douglass had never been willing to accept their evidence. It was beam HH39 that cleared away all doubt.

This is a vivid account of how tree-ring dating is carried out; it shows how in spite of many difficulties the persistent investigator finally achieves his aim, and it should encourage others to undertake similar work in other suitable regions.

Difficulties encountered in dating ruins. Individual dated ring-series, however, are no reliable evidence for the exact date of the ruin from which they were taken. It is necessary to make sure that the outermost ring preserved was the last put on by the tree before it was felled; if the beam is worn, one has to allow for an unknown number of missing rings.

If the dated beams of a ruin are compared, it is usually found that the felling dates cover a period of several, sometimes many, years. The difficulties arising out of this have been discussed at

some length by Roberts (1939). If the majority of beams yield dates within a year or two, there is little doubt about the time of the erection of the building. Older beams are then regarded as material salvaged from earlier structures, and later beams as replacements.

Records of the Californian 'big trees'. It is natural that at an early date investigators of tree-rings cast an eye on the forests of the 'big trees', *Sequoia washingtoniana*, found along the western slopes of the Sierra Nevada in California. These trees are not only the largest single organisms known at present to exist, but also —as tree-ring analysis has shown—the longest-lived. In 1911, Huntington began to study the rings of the *Sequoia*-trees, and he as well as Douglass have since done a great deal in interpreting the results of the countings. More recently, Antevs, an authority on varved clay analysis (see the following chapter), undertook a careful survey of the work so far done on *Sequoia* (Antevs, 1925). After the elimination of disturbing factors several climatic curves have thus been obtained for not less than 3,000 years backwards, but it has as yet not been possible to use this evidence for direct dating of prehistoric sites or objects in North America.

Tree-ring dating in Sweden. The *Sequoia*-curve has been applied, however, to date a prehistoric site far distant from California, namely in Sweden. Ebba Hult de Geer, collaborator of Gerard de Geer, the inventor of the varved-clay analysis (see p. 20), studied the growth-rings in the poles of a prehistoric water-fort found in Lake Tingstäde Träsk in Gotland. She compared the ring-sequences with the *Sequoia*-curve of California and believes she has obtained satisfactory agreement in the records of the fifth and sixth centuries A.D., at which time therefore the fort is considered to have been erected. It is claimed that the main bulwark was built about A.D. 450 and that the last additions were made about A.D. 585. Although the author mainly relies on the *Sequoia*-curves, a curve drawn from Swedish pines also is given in the paper. (Note (5), p. 388.)

Teleconnexion. This practice of correlating series of annual layers (tree-rings or clay-varves) over wide distances is called *teleconnexion* by G. de Geer and his fellow-workers. It will be discussed more fully in the second chapter (p. 39), since much importance has been attached to it in respect of the interpretation of clay-varves. Here it suffices to say that this practice has not met with general approval.

C. CYCLES IN TREE-RING SERIES

Teleconnexion is to some extent rendered possible by the occurrence of cycles, or rhythmic variations, in the tree-ring curves. They are caused by a more or less regular alternation of groups of relatively thick and relatively thin rings which obviously correspond to changes of certain external factors influencing the formation of wood. For many years Douglass has been particularly anxious to study the

cycle phenomenon and he has obtained results the importance of which extends far beyond the limited scope of tree-ring analysis as we shall see later on.

Sunspot cycle and tree-rings. In some ring-records of trees from temperate Europe, where a fair amount of precipitation falls in summer, a simple cycle of an average length of a little over 11 years is very obvious (fig. 4). Curiously enough the average duration of the sunspot cycle [1] also is just over 11 years (Clayton, 1939). After a careful examination of the available evidence Douglass identified this tree-ring cycle with the cycle of the sunspots.

Douglass, Glock and others have shown that this single-crested 11-year cycle in the tree-rings is characteristic of regions with a comparatively damp climate, i.e. where droughts are rare in summer. So they found that it is prominent in the Recent mammoth-trees (*Sequoia*) of California, in accordance with the foggy summer climate.

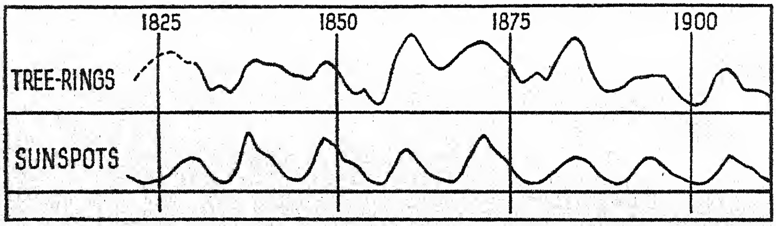


FIG. 4.—The single-crested 11-year cycle exhibited by north European pine trees in the nineteenth century. Upper curve: tree-rings. Lower curve: fluctuations in the number of sunspots during the same period. The agreement of the two curves is remarkable.—Based on Glock (1937, fig. 39).

They discovered the same type of oscillation in the rings of *Sequoia*-trunks of Tertiary age from the same district also, and therefore argued that the Tertiary climate must have been similarly damp as that of to-day. Moreover, the single-crested 11-year cycle occurs in tropical rain-forest regions, too, as has been established for two kinds of west African woods of the mahogany type (Zeuner, 1938).

In districts such as Arizona, however, where the climate tends to be dry in summer, two oscillations instead of one are frequently observed in the tree-ring records during an 11-year period. This short cycle (fig. 5) is called the Hellmann cycle, and two of them combined are often called the 'double-crested 11-year cycle'.

The difference between the double-crested and single-crested

[1] The dark spots which are observed on the sun vary periodically. It has been found that their periods are between 5·6 and 19·9 years, though of 96 spots no fewer than 63 have periods between 9·9 and 11·9 years. The composite periodicity of the sunspots is about 11·2 years (Clayton and others) or 11·4 years (Douglass and others); it is, of course, not constant. For details, consult Clayton's recent papers, also Schostakowitsch (1928) and other papers in the same volume of the Meteorol. Zs.

cycles is puzzling from a climatological point of view. One is inclined to think that tree-growth depends entirely on rainfall and temperature. It certainly does depend on these two factors to a large extent. Schwarz, for instance, found that the Scotch pine (*Pinus silvestris*) in Germany follows the fluctuations of temperature, and Hesselman established the same for Sweden. It also became clear that in the comparatively damp climate of temperate Europe the growth in thickness of the trees depends more on temperature than on the amount of rainfall. Douglass's work on the Arizona pine, on the other hand, showed clearly that in drier regions the thickness-growth of trees responds primarily to changes in the quantity of rainfall.

Thus there is no doubt that temperature and precipitation do influence the growth of trees to a certain extent, though not exclusively and not everywhere in the same manner.[1] A great many

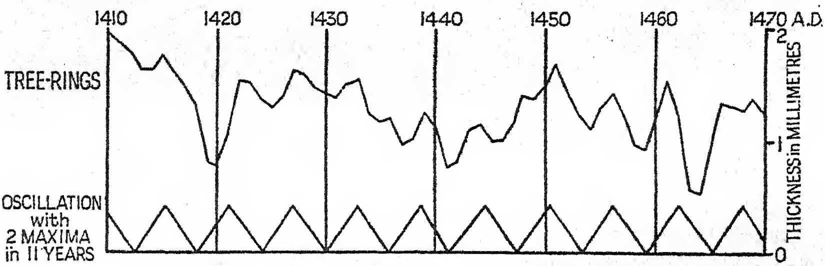


FIG. 5.—The double-crested 11-year cycle exhibited by Arizona pines in the fifteenth century. Upper curve: tree-rings, thickness in millimetres. Lower curve: a regular succession of two oscillations in 11 years, for comparison. The sequence of maxima and minima in the tree-ring curve agrees fairly well with a double oscillation in 11 years.—Based on Glock (1937, fig. 38).

tree-ring records, in fact, show no distinct relations between precipitation or temperature, and the thickness of the rings. The records of *Sequoia* were considered by Douglass as in fairly good agreement with the rainfall curve, but Antevs admits this only for limited periods and finds that on the whole the correspondence is not good. It is particularly noteworthy that the great precipitation in 1862, 1867, and 1868, is not recorded by wide rings in the *Sequoia*-trunks. Thus, the relation between climatic conditions and tree-growth appears to be a complicated matter, and the possibility that factors other than precipitation and temperature influence the growth of trees has to be considered.

Solar constant and tree-rings. The fact that the cycles observed in tree-ring sequences agree so closely with the sunspot cycle strongly suggests that one of these factors may be solar radiation, especially since an indirect influence of the sunspots on the tree-rings via

[1] The species of the tree also plays an important part, some being sensitive, others not. Most of the work has been done on Conifers.

precipitation or temperature can apparently be ruled out. Only occasionally may be found a resemblance of the curves of rainfall or temperature of a certain district to the curve of the sunspots, though some connexion of the average fluctuations of atmospheric pressure with the sunspot cycle has been established by Clayton (1939, 1940 [1]) and others. If, therefore, the deviations from the normal of the climate of a district show less resemblance to the sunspot curve than do the tree-rings, it becomes probable that the influence of the sunspots on the trees is a more direct one than through the meteorological conditions resulting from an influence of the sunspots on the climate.

What then is the actual effect of the sunspot cycle on the growth of trees? This question cannot be answered at present. We have to content ourselves with stating the fact that some sort of connexion exists. Sunspot maxima increase the value of the *solar constant* [2], particularly owing to an increase in ultra-violet radiation. According to H. T. Stetson this has been established by Dr. Pettit's work in the Mount Wilson Observatory in California. Professor Stetson has written a stimulating book on sunspots and their effects which contains a great deal of information concerning the influence of the sunspot cycle on life generally. The reader is left in no doubt that the influence of solar cycles on life as well as on climate is considerable, and also that it is probably produced by correlative fluctuations of radiation.

There were scientists who for many years regarded with reserve Douglass's striking discovery of the sunspot cycle in the records of tree-rings. But the evidence which he and others have been able to accumulate has in the course of time convinced almost everybody, and in several cases observations which at first glance seemed to contradict his claims have later turned out to corroborate them perfectly. One of the most surprising cases of a 'happy end' to a worrying discrepancy between theory and observation is that of the absence of the 11-year cycle in the Arizona tree-ring records between 1645 and 1715 of our era, when it was replaced by a 10-year cycle. We cannot conclude this short introduction to tree-ring analysis better than by quoting H. T. Stetson's words telling how the solution was found.

One day early in 1922 Professor Douglass's morning mail brought a letter from Professor Maunder of the Royal Observatory in Greenwich, England. In this letter Professor Maunder told Professor Douglass that he had been searching into early records of sunspot observations with some surprising results. This search of the English astronomer

[1] 'The smoothed plus and minus annual departures from normal pressure observed in the earth's atmosphere are displaced in position in unison with variations in intensity of sunspot maxima.' (Clayton, 1939, p. 1.)

[2] The amount of radiation received from the sun, measured in gramme calories per square centimetre per minute, at the upper limit of the atmosphere.

had revealed that a great dearth of sunspots had been observed during the entire period from 1645 to 1715. Maunder knew nothing of Douglass's difficulties but merely wished to convey to him the information of this remarkable discovery in sunspot data. He ventured to remark to the Arizona scientist that if there were any real connexion between his tree-growth theory and the sunspot cycle, he should have found evidence lacking as to sunspots in his tree-ring records between 1645 and 1715. Thus we see how a strange failure of sunspots to appear during the middle of the seventeenth century actually corroborated Douglass's findings at a time when he nearly gave up the idea of the connexion between sunspots and tree-rings on account of an apparently unexplainable discrepancy.

Summary. Summarizing the results so far obtained by tree-ring analysis the following three points may be emphasized.

(1) In spite of the limited applicability of tree-ring counting to archaeological dating a reliable calendar has been established for the dwelling-sites and cultural phases of the south-western United States, covering 1,500 years. This is a spectacular success indeed.

(2) Countings, which cannot yet be correlated with prehistoric phases in a satisfactory manner, extend back for 1,900 years in Arizona and for more than 3,000 years in California. They will provide the basis for further dating work.

There are obviously good chances for applying tree-ring dating to other regions, including temperate Europe, but progress will be slow and a good many years may elapse before reliable results are achieved even for the latest prehistoric periods, as these are earlier in Europe than in America. Yet tree-ring analysis may one day provide a help in dating historic objects in Egypt, in other parts of the Mediterranean, or in temperate Europe.

(3) A definite connexion has been established between the growth of trees, the climate, and the cyclic changes in solar radiation. The sunspot cycle of 11 years is prominent in the tree-ring records. This result is of more general importance. It agrees well with observations bearing on the varved clays (see p. 43) and suggests that even minor fluctuations of solar radiation have left traces on the earth. It therefore indirectly supports the dating methods based on major fluctuations of solar radiation as described in Chapters V to IX.

PART II

DATING THE METAL AGES, NEW AND MIDDLE STONE AGES, AND THE CLIMATIC PHASES WHICH FOLLOWED THE ICE AGE

(*Back to about* 15,000 *years ago*)

CHAPTER II

VARVE ANALYSIS

A. MODE OF FORMATION OF VARVES, AND METHODS OF INVESTIGATION

De Geer's conception of counting annual layers in sediments. The credit of having designed the first reliable method of dating geological events in years belongs to Baron Gerard de Geer in Stockholm. As long ago as 1878, during his field-work in the Stockholm region, he was struck by the regularity of the lamination present in certain clayey deposits.[1] Investigation proved that the laminae were annual layers deposited in meltwater basins by the retreating ice. Such layers are called '*varves*' in Swedish, and the deposits are known to geologists as varved clays or sands. De Geer soon began to study the varying thickness of the varves, to identify them in different sections, and to count them wherever possible. Since then, the method of varve analysis has been considerably improved and successfully applied to the varve sections formed in front of the retreating margin of the ice-sheet of the Last Glaciation in Scandinavia, Finland and elsewhere. In addition to de Geer's own and his collaborators' work (de Geer, 1940), I may refer to Sauramo's countings in Finland (1923, 1929), to Antevs's in North America (see Antevs, 1925*a*, with chapter on varved sediments and exhaustive bibliography), and to Vierke's (1937) in Pomerania.

The varve method is the earliest geochronological method and, therefore, well known to geologists and archaeologists. It also is one to which the term 'geochronology' has been most often applied.

De Geer's varve method is necessarily restricted in its application. It leads to a fairly complete record in years of the late Glacial and Postglacial periods, but beyond that there is little hope so far of arriving at more than time-scales for isolated periods which cannot be linked up in years with Recent times (see p. 36).

Formation of varves. Varved clays were, and still are, formed where glaciers discharge their meltwater into quiet water. The latter may be a lake, in many cases one dammed up by a terminal

[1] An informative appreciation of de Geer's work is contained in the obituary written by E. B. Bailey (1943).

moraine built by the ice at an earlier stage (fig. 6), or it may be a bay or sound of the sea, or even a quiet river.

Let us consider the case of a lake. In summer, when melting is intense, a lake ponded up in front of the ice receives a large supply of meltwater which is laden with a fine suspension of sand and clay derived from the morainic matter carried in and under the glacier. This suspension, called 'Gletschermilch' = glaciers' milk, because of its opaque, often whitish colour, gradually spreads over the whole lake and very slowly settles down. During this process of sedimentation the coarser grains contained in the suspension fall to the bottom more rapidly than the finer, and they form the first layer of the deposit. This layer, however, is never quite pure since a certain amount of fine grains which happen to be near the bottom will be incorporated in it. Yet on the whole coarser material settles first from the suspension, finer material later, and the finest

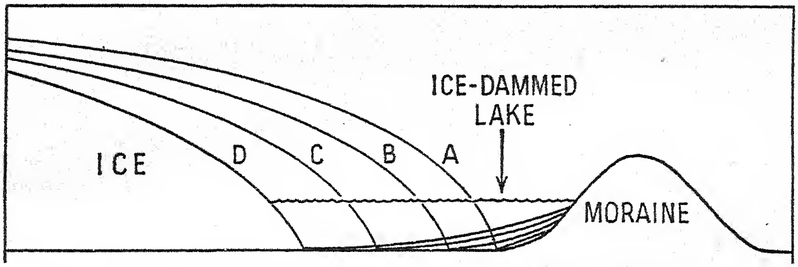


FIG. 6.—Formation of annual varves during the retreat of the ice from a moraine. Successive winter-halts of the ice, A, B, C, D. Each varve ends at the line to which the ice had receded in the particular year.

may remain in suspension until winter comes and the gradual freezing up of the lake helps it eventually to reach the bottom. In the following year, after the lake has lost its cover of ice, the process is repeated, and so forth. The result is a regular sequence of annual 'varves' (pl. IV, figs. A, B), which often are as conspicuous as growth-rings of trees, owing to the change of colour accompanying the change from coarse grains to fine.

Composition of varves. The size of the grains composing varves is usually small. Occasionally, very thick varves may be observed composed of sand below (grain-size chiefly 1·0–0·1 mm.) and silty clay in their upper portion (grain-size under 0·1 mm., chiefly 0·1–0·01 mm.). An example of such coarse varves is shown in pl. IV, fig. A, from Opava (Troppau) in the Czechoslovakian Sudeten Mountains, where subaerial meltwater gravels are overlain by varved lake deposits, the first six varves being thick and exceedingly sandy. Another instance, from Sperenberg near Berlin (pl. IV, fig. B) represents a section of sandy varves which however are finer

than those at Opava. Very fine-grained, clayey varves are, as a rule, thin.

Fine-grained varve deposits are much more frequent than coarse ones. Sauramo analysed a great many Finnish samples, and from his figures for fourteen of these it is seen that in the average not less than 85·7 per cent. of the material is under 0·02 mm., and 52·1 per cent. under 0·002 mm. This means that more than half of the material is finest colloidal clay-matter.

Chemically the varve deposits offer no special interest.

Thickness of varves. In the majority of varved deposits the individual laminae average between a few millimetres and a few centimetres in thickness. Sometimes they may be abnormally thin, measuring as little as a fraction of a millimetre. On the other hand

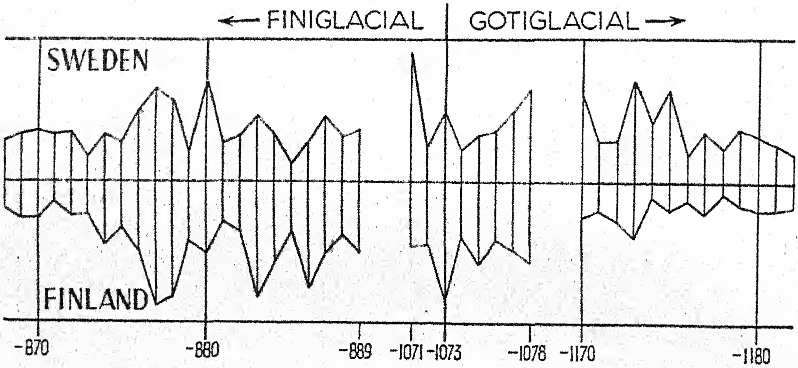


FIG. 7.—Examples of de Geer's varve plots, showing significant agreement. Sweden above, Finland below. Note that the maxima of Finland are reversed. The earliest varves appear on the right. Years on de Geer's time-scale, counting from the Bipartition (Ragunda drainage varve).—After de Geer, 1930.

unusually thick annual layers are not infrequently observed, and Sauramo records some measuring as much as 40 cm. It is obvious that exceptionally thick or thin varves make the plotting of long series on the same scale somewhat difficult, but such varves also afford most valuable land-marks in a sequence which, perhaps, is otherwise fairly uniform. De Geer's well-known varve-curves from Sweden (figs. 7, 12) mostly show variations in limits smaller than those given above.

Varves and moraines. Since varves demand for their formation quiet water in the neighbourhood of glaciers, they are almost invariably connected with some kind of moraine. Very often a terminal moraine, formed at an earlier stage, dammed up a lake fed by meltwater, into which the gradually receding ice-front discharged a suspension of mud. This mud, when deposited, formed the varves, as described above. As the ice-margin retreated the varves followed

it, and, assuming a northward retreat, each succeeding varve is found to begin farther north than the preceding one (fig. 6), its northern limit indicating the exact position of the ice-margin in the year of formation of the varve in question. If the gradual retreat of the ice-margin was interrupted by a stationary phase or a slight re-advance, a new terminal moraine was formed. The duration of such a halt can be determined from the varves deposited in front of the moraine. When the ice-recession was once more resumed the process of varve-formation continued normally. Conditions of course varied a great deal locally and the story given here must be regarded as no more than an example.

The ice-recession in Scandinavia and Finland usually proceeded at a rapid pace (between — 1150 and — 600 of the Swedish Time-scale it varied between 120 and 400 m. per year; de Geer, 1940, p. 154), and the areas of ponded water were very extensive. The individual varves, therefore, often cover wide areas, and this fact is of considerable help in identifying them in sections which are distant from one another. Furthermore an overlap of sections occurs frequently, the top varves of one lake being of the same age as the bottom varves in another lake which began to deposit varved sediments later than the first.

De Geer's method of investigation. Thus, in theory, all one has to do is to count the varves and to measure their thicknesses in as many sections as possible and then to try and identify the overlaps, duly considering all the known geological facts. When, in 1905, de Geer started field-work on a large scale, he applied the simple practice of smoothing with a suitable instrument the sections in the pits and transferring the thicknesses of the varves directly to long strips of paper. In the laboratory the records thus obtained were used to construct curves which in turn were cross-identified with others in the same way as described for the annual growth-rings of trees in the previous chapter (fig. 8). This method has the great advantage of allowing of expeditious work, and there is little need to take home heavy sample-columns of the deposits, provided the varves are clear and not too thin. It has obviously been applied most successfully in Sweden, but in areas where the varves are very thin, this method is no longer practicable.

Sauramo's method. Moreover, Sauramo was able to prove that the thickness of an individual varve need not be constant over the whole of its area, and that, in deposition-areas not directly connected, varves of the same year may be quite different. He therefore prefers to supplement the original method of cross-identifying on the base of relative thickness only by a close study of other features of the varve-sequences. He says:

A better method must be independent of the variation of thickness of the varves, the inconstancy of which is the main source of trouble,

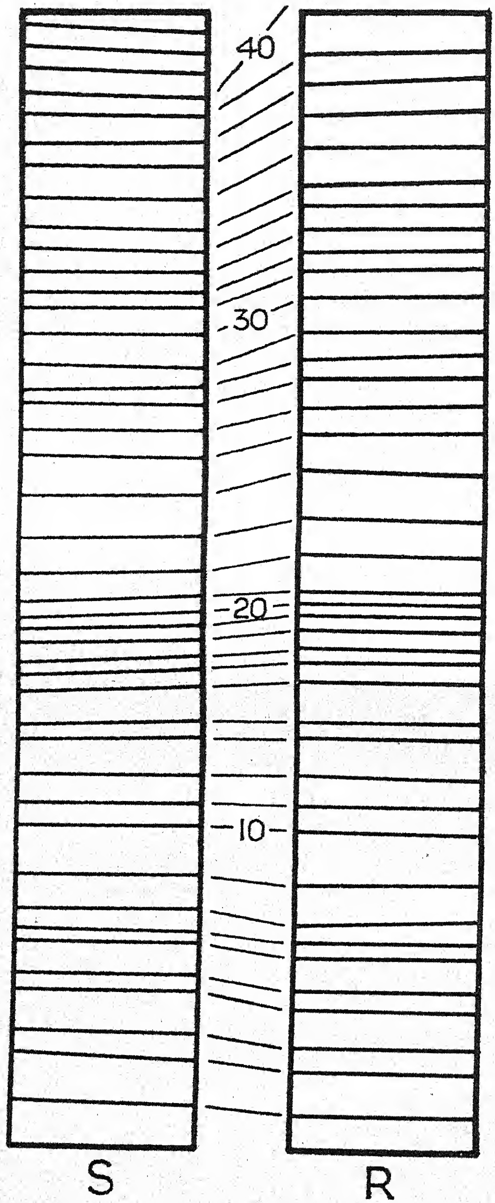


FIG. 8.—Example of cross-dating of two sample columns of varved deposits, from Finland. Localities, Sipilä (left) and Rauhaniemi (right), connected by M. Sauramo. Note the group of very thin varves around 20, and the very wide varves between 20 and 30.—Half natural size.—After Sauramo, 1923.

and rely upon other characters, inherent in each individual varve or group of varves and more constant than the relative thickness. Such characters in fact exist among the physical properties of the sediments. Of course, primary properties only must be considered and not secondary ones, such as those due to weathering, or the action of ground water. Those primary properties that may serve for the purpose of connexion are: colour of the sediment in the state of natural humidity above the ground water level, coarseness of grain and hygroscopicity, plasticity, arrangement of grains of different coarseness in the varves, i.e. whether the coarser and finer materials are mixed together or arranged in separate layers, and in the latter case, whether these layers of definite coarseness of grain limit each other with sharp lines or by gradual transition.

Such characters are, as a rule, not confined to one or two varves only; they are typical of parcels of varves. It is possible, therefore, to recognize certain particularly characteristic groups of varves or, as Sauramo calls them, *varve series*. In order to identify varve series it is necessary to take sample-columns from the sections and to study them in the laboratory. Sauramo thus investigates first the larger units and, having identified these, proceeds to the smaller, i.e. the individual varves. There is no doubt that in this way the possible error is reduced to a minimum.

Construction of plots or curves. As in the case of tree-ring analysis, the varying thickness and other features of the annual layers have to be plotted. The most convenient method for varve-plotting is to mark the varves at equal intervals along a horizontal line and to show their thicknesses at right angles to this. A connexion of the top ends of the thickness lines then yields a kind of 'curve' [1] which is easy to read and to interpret. The earliest varves may be shown either on the right or on the left.

Biennial maxima. Such curves often attain considerable length and it then becomes difficult to compare several of them, to identify similar series, and to correlate these. For this reason, de Geer introduced another kind of plot which is derived from the original curve. He calls this the *method of the biennial maxima*. The idea is to mark down only the 'maxima' shown by the original curve (fig. 11). A 'maximum' [1] results from an increase of varve thickness from a certain year to the following, and a decrease in the year thereafter. Such sequence thinner-thicker-thinner requires two years for its formation; hence the term 'biennial' maximum. De Geer plots biennial maxima, as shown in fig. 11, by short marks on a horizontal line. The marks are directed upwards for odd and downwards for even years. As a rule, de Geer does not plot biennial maxima when they occur singly, but mostly when they appear in groups of two or more (de Geer, 1934).

[1] Mathematically, the 'varve curve' is not a curve, and a 'biennial maximum' not a maximum. Both terms are unfortunate, but as they are in common use, they are best retained.

It must not be overlooked that the plots of biennial maxima no longer give a complete record of the varve section. They single out a particular kind of oscillation. Although they do help to establish likeness in varve-records from different localities they cannot claim to be as accurate as the original curves, and certain risks are implied in their application. One example may suffice to make this clear. A biennial maximum in which the thickest varve is about twice as thick as any of the thinner is, of course, a perfectly plain and characteristic feature, but a series of varves of, for instance, 16 mm., 17 mm., 14 mm. also represents a biennial maximum. In a neighbouring locality, however, the sequence may be 16 mm., 15 mm., 14 mm., and no maximum is observed. Where slight variations of thickness decide between the presence and absence of such maxima, the method obviously cannot work satisfactorily.

B. VARVE CHRONOLOGY

Results of countings in Sweden. Before entering upon the question of dating climatic events and human industries by the varved clay method the outstanding results of varve counting have to be reviewed briefly. In Sweden, de Geer succeeded in counting varves along sections from the extreme south up to a point high in the mountains where the melting ice-cap finally became divided into two parts, remnants of which are still preserved (fig. 9).

The zero-varve. Not far from the place where the bipartition occurred, at Ragunda, a lake existed until 1796, when it was accidentally drained. The varves of this lake added 3,000 years to the time-scale, and among them a particularly thick varve, which de Geer interpreted as the result of the great run-off of ponded water which followed the bipartition. Since he was able to recognize this varve in many sections, he chose it as the zero-point of his chronology. He marked all the later years with a *plus*-sign and called them collectively *Postglacial*, whilst the years preceding it (with *minus*-sign) are grouped into the *Finiglacial* phase (see de Geer, 1940, p. 171).

Link-up with present day. The varve series of Lake Ragunda proved disappointing in so far as they did not provide the expected link with modern times. Varve formation had ceased long before A.D. 1796. But along the Ångerman River, in northern central Sweden, Lidén (1913, 1938) found Postglacial varves which continued into Recent deposits. From these, Lidén determined the calendar date of the zero-varve as 6839 B.C. This date marks the beginning of the Postglacial in de Geer's sense (1940, p. 178).

End of Glacial and beginning of Postglacial. There has always been a difficulty in drawing a line between the last stages of the Ice Age, which naturally have to be included in the Pleistocene, and

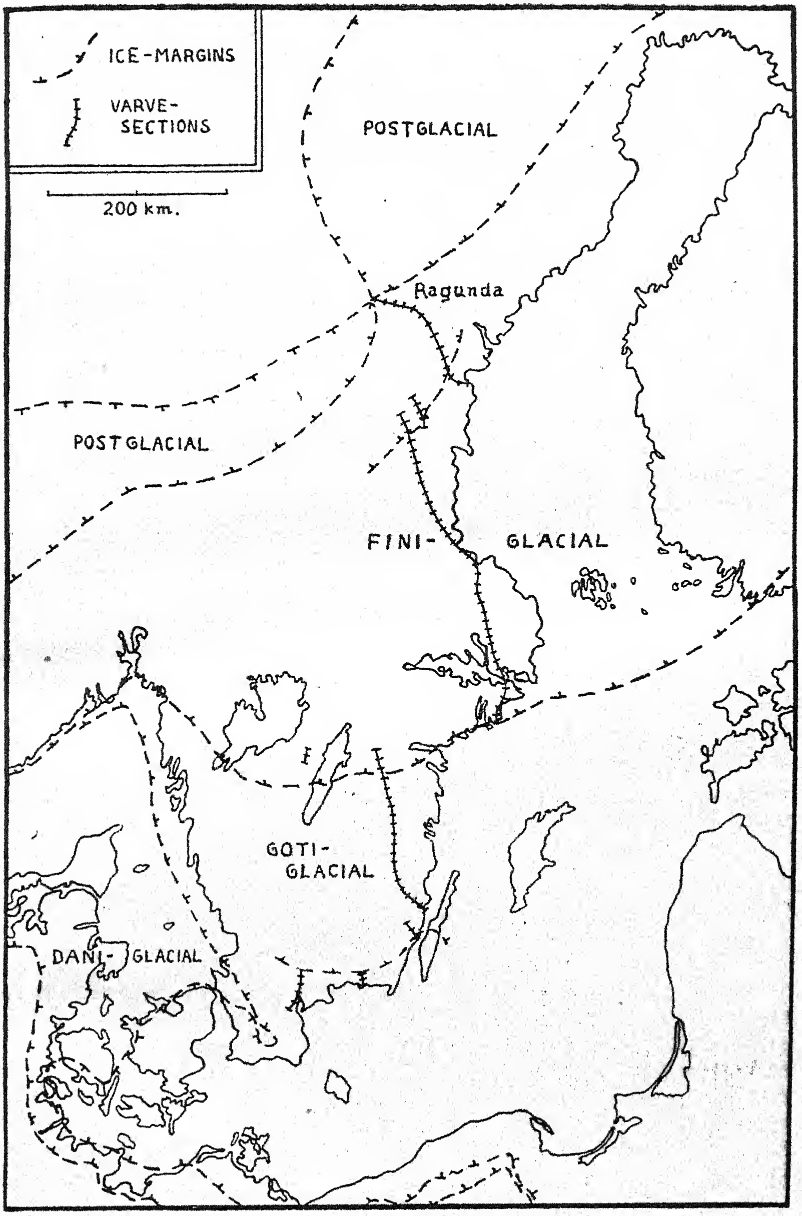


FIG. 9.—Ice-recession and varve countings in Sweden, according to de Geer's report to the International Geological Congress at Stockholm, 1910. The varve sections are shown to cover almost the entire distance from the Dani-Gotiglacial moraine to Lake Ragunda.—After de Geer (1912).

the early Postglacial or Holocene. As conditions did not improve suddenly, the retreat of the ice having been more or less gradual, no clear distinction can be made which would apply not only to Scandinavia but to the rest of the world.

It is obviously advisable to appoint some event as the dividing mark and to apply it arbitrarily everywhere, even in regions where no corresponding climatic evidence is available. But the difficulty is, which event to choose. De Geer took his zero-point, corresponding to 6839 B.C., as designating the end of the 'late Glacial' and the beginning of the 'Postglacial'. Jessen, Nilsson, Gams, and others, however, prefer to use the halt at the central Swedish moraines, i.e. the limit between Gotiglacial and Finiglacial, at about 7912 B.C. This coincides with the breakdown of the glacial anticyclone (Zeuner, 1944, p. 157), and with the beginning of great changes in the vegetation of northern Europe; it is therefore more easily recognizable outside Sweden, and should be preferred generally.[1]

Finiglacial phase. The extension of the time-scale from the zero-varve into the past depends chiefly on sections in the Stockholm area, where the method of varve chronology was first conceived and practised by de Geer and his 20 collaborators. This is the only area for which a sufficient amount of evidence has so far been published in detail. Several series of measurements, which agree well, extend back to − 1400 (= 8239 B.C.); they are of especial importance since they comprise the belt of the great *Central Swedish Terminal Moraine,* a conspicuous zone of hills which marks a well-defined halt of the ice during its retreat from the Last Glaciation. In order to assign a definite year to this halt, an event was chosen which left traces in many varve sections, i.e. the draining of the Baltic Ice-lake. This event occurred in the year − 1073 (= 7912 B.C.), according to de Geer. It is taken as the beginning of the Finiglacial phase, and the end of the Gotiglacial phase of the ice-retreat. De Geer (1940, p. 147) describes it as follows:

> Immediately above the Goti-Finiglacial limits the varves become thicker and exhibit at the same time a very striking change in colour and consistence, which has been traced to that very point in the province of Vestergötland, where the land-ice border receded from the north end of Mt. Billingen. This was the northernmost cape of the South-Scandinavian land barrier, which had been damming up the great South-Baltic ice-dammed lake. When the ice-dam thus became opened, the ice-lake was lowered by some 28 m. down to the sea-level, and

[1] The limit Postglacial-Pleistocene is the first stratigraphical boundary to be defined in terms of years. It is only a matter of time that a figure will be agreed upon to divide the Pleistocene from the Pliocene (see p. 337). The purely geological or palaeontological divisions become increasingly difficult to maintain as research goes on, and no doubt the day will come when all geological divisions are defined by absolute time rather than unconformities and appearance and extinction of certain forms of life.

an under-current of sea-water entered into the Baltic basin. (See this book, figs. 16–17.)

This catastrophe happened in the year −1073. Before that year the varves were rather grey and silty. Immediately afterwards they became thicker, brown and more rich in fine clay, probably because a greater portion of the sediment, when entering into the brackish water, at once became flocculated and deposited in the neighbourhood of the ice-border.

Gotiglacial phase. The *Gotiglacial* phase is reckoned by de Geer to begin with the withdrawal of the ice from certain moraines in southernmost Sweden (South Scanian Moraines). Since 1912, de Geer has tentatively connected the South Scanian Moraines with the Baltic Terminal Moraines of the European mainland (the Pomeranian phase, see p. 113) as shown in fig. 9. The South Scanian Moraines form a peculiar loop near the town of Bara, enclosing a small ice-free area, and are supposed to continue from there across the Danish Isles to Jutland, where they turn south and southeast to link up with the Baltic Terminal Moraine. This arrangement of terminal moraines, if it can be substantiated, is not impossible; it might be due to an icestream pushing forward in the depression now occupied by the Baltic Sea, whilst the moraine north and east of the Bara loop marks the edge of the Swedish ice that came down from the Scandinavian mountains. Acceptance of de Geer's combination means that any date for the stage of the Bara loop would directly apply to the Baltic End Moraine, or the Pomeranian phase, also.

In 1926, de Geer gave the common age of this morainic belt (which marks the beginning of the Gotiglacial) as approximately between − 9650 and − 9437, or 16489 to 16276 B.C. (roughly 18,000 years before the present [1]. In 1928, and again in 1933, de Geer reported that he had used wrong figures. The figure to be inferred from his suggested corrections was somewhere between 12000 and 14500 B.C. Unfortunately his latest, comprehensive, book (1940) does not discuss the time-scale of the Gotiglacial, and the original measurements have, to the best of my knowledge, never been published. On his plate 90, he supplies a general time-scale, noting the *duration* of the Gotiglacial as 6,379 years. This, again, is an accidental slip since, on plate 87 B, the *beginning* of the Gotiglacial is indicated at about − 6380, i.e. 13219 B.C., or about 15,000 years ago.

This is the best date at present available for the beginning of the retreat from the South Scanian Moraine, or the beginning of the Gotiglacial as defined by de Geer.

[1] In de Geer's map there appears, by mistake, 18000 B.C. He corrected this in 1928, but the error has caused much confusion in literature.

FIG. 10.—Morainic belts and phases of the Last Glaciation. Note that according to this version, the Pomeranian moraine (III) is distinct from the phase of the Bara loop (V). Note also the conspicuous triple belt of the Central Swedish Salpausselkä moraines.—After Vierke (1937).

Problem of connexion of terminal moraines across the western Baltic. As has been said above, de Geer considers the Pomeranian (Baltic End Moraine) as contemporary with the beginning of the Gotiglacial in South Scania. De Geer's connexion has, however, been contested, especially by Danish workers. There are now two different alternatives, which renounce part or the whole of the great lobe of Baltic ice extending to the Danish Isles. Antevs (1928) regarded the Pomeranian as decidedly older than the South Scanian Moraine and attributed them to two successive and approximately concentric stages of retreat. If he is right, the age of the Pomeranian must be greater than that of the South Scanian by an unknown amount, which may be considerable.

More recently, Vierke (1937) has combined the results of various workers in a new map (fig. 10), in which the Bara lobe is preserved, but connected with a *north Pomeranian* belt of moraines which is later than the terminal moraine usually called the Pomeranian stage (this is Vierke's south Pomeranian belt). This interpretation, too, makes the Pomeranian stage proper older than the South Scanian, though less so than does Antevs's interpretation.

As de Geer and everybody else have in practice identified the Gotiglacial with the retreat from South Scania to the Central Swedish Moraine, the term *Daniglacial* of de Geer would apply to the chronological gap between the South Scanian and the Pomeranian (*sensu stricto*) stages.

Furthermore, though de Geer's estimate of 18,000 years for the Pomeranian phase has been accepted very widely, it no longer can be regarded as based on direct evidence. It was suggested in connexion with the South Scanian Moraine, the age of which has since been much reduced. It may, after all, not be far off the right mark for the Pomeranian, but further research is urgently needed either to confirm it or to replace it by a more accurate figure.

Thus, the results of the varve method in Sweden and north Germany are far from being satisfactory for the earlier phases of the retreat of the Last Glaciation and further research, especially varve countings between the Pomeranian and South Scanian stages, are pressing requirements. All one can say at present is that the Pomeranian is at least about 15,000 years old, and probably more.

For the later stages of the retreat of the ice, from the Central Swedish Moraines onwards, however, the figures appear to be more reliable, and accurate enough to provide a time-scale for the development of the Baltic Sea as well as for the Mesolithic and Neolithic industries of man (Chapter IV). The following table summarizes Swedish varve chronology:

Phase	Years before or after zero (de Geer)	Date (based on Lidén)
Present Day	+ 8739	A.D. 1900
Postglacial (de Geer)		
Ragunda drainage varve	± 0	6839 B.C.
Finiglacial		
Ice-lake drainage (Central Swedish Moraine)	– 1073	7912 B.C.
Gotiglacial		
South Scanian Moraine	– 6380	13219 B.C.
Daniglacial		
Pomeranian (Great Baltic) End Moraine		

Results of countings in Finland. On the other side of the Baltic, varve countings have been carried out independently in Finland, chiefly by Matti Sauramo. He accepted as zero-point the beginning of the ice-retreat from the second of three closely connected and excellently preserved morainic belts called Salpausselkä. This zero-point is earlier than the Swedish one. Since the Salpausselkä moraines are reminiscent of the Central Swedish Moraines in structure and preservation, many authors have considered the two groups as contemporary, especially as it is easy to connect them across the Baltic (fig. 9). At present, however, the view predominates that they are not of exactly the same age. Antevs (1928) puts the Central Swedish Moraine about 300 years later than the second Salpausselkä, and Sauramo connects the Central Swedish Moraine with the third Salpausselkä stage. In 1929, Sauramo deplored that the Swedish results had not yet been published in detail and that one had to rely on figures instead of detailed evidence when trying to establish a correlation between Finland and Sweden. The Finnish scale is several hundred years longer than the Swedish. For this reason Sauramo, for some time, adopted de Geer's positions of the ice-margin only and applied to them the numerical results obtained in Finland. Lately, however, he has been able to accept some of de Geer's figures (1939). The ensuing correlation of the two chronologies is shown in the following table.

	de Geer		Sauramo	
	Relative	Years B.C.	Relative	Years B.C.
Ragunda drainage varve	± 0	6839 B.C.	c. + 1350	6800 B.C.
Ice-lake drainage (Central Swedish Moraine)	– 1073	7912 B.C.	+ 292	7858 B.C.
Finnish Moraine, second Salpausselkä	– 1365	8204 B.C.	± 0	8150 B.C.

Considering that these figures cannot be more than approximate, the agreement must be regarded as excellent.

Antevs's work in North America. Not only in Fennoscandia but in North America also has the varve method been applied successfully. Here, E. Antevs is the leading worker. He studied the ice-recession from the terminal moraines on Long Island near New York to as far as northern Ontario. The difficulty in North America is that no link with the present day, such as the varves of the Ångerman River, has so far been found, and that estimates have to replace countings for certain portions of the time-scale.

Antevs used for his countings two independent zero-points, corresponding to two long series of sections. The first series runs up the valley of the Connecticut river, and the second is situated north-east of Lake Huron. The gap between the two series is partly filled by the calculation of the recession of the Niagara Falls. The northern terminus of the second series is at Cochrane, near the Abitili river, and the final recession of the ice from there is still largely a matter of conjecture. The sequences from New York to Cochrane were summarized twice by Antevs (1928, 1931):

	Antevs, 1928	1931
Long Island moraines (Ronkonkoma to Harbor Hill)	c. 2,000	2,000
From Harbor Hill to Hartford, Conn.	c. 5,500	5,500
Hartford to St. Johnsbury, Vt.	4,100	4,100
St. Johnsbury to Stony Lake, Ont.	x	} 10,000
Stony Lake to Mattawa Valley, Ont. (based on Niagara Falls)	c. 13,000	
Mattawa to mouth of Montreal river on Lake Timiskaming, Ont.	y	3,775
Mouth of Montreal river to north of Cochrane, Ont.	2,000	2,025
Re-advance to Cochrane	—	200
	$26{,}600 + x + y$,	27,600 years

Probably c. 28,000 to 29,000 years

One notices that, in the first column of this table, the gaps x and y are considered as small, amounting to 1,400 to 2,400 years in all. The time which has elapsed since the Cochrane stage up to the present day (z) consists, as far as eastern North America is concerned, of the period required for the final melting of the ice (m) and the period from the disappearance of the ice to the present day (u). The estimates for z ($m + u$) have varied considerably as research proceeded.

In 1931, Antevs revised his earlier estimates. Fresh work on the Niagara Falls now caused him to reduce the entire phase between St. Johnsbury and Mattawa to about 10,000 years (formerly $13{,}000 + x$), whilst y is estimated at roughly 4,000 years. This gives a total of 27,600 years, to which has to be added the interval z.

This interval z is given by Antevs (1931) as 9,000 years, a period

which Bryan and Ray (1940) suppose to have been taken from the European reckoning. If this is right, Antevs considers Cochrane as the equivalent of the Lake Ragunda stage of the Scandinavian ice-retreat. A somewhat generalized summary of Antevs's calculations and estimates for the whole of North America is given by Howard (1935), as follows:

Postglacial, duration 8,500 years	Late 4,000	Modern Recent
	Middle 3,500	Temperature distinctly higher than to-day
	Early 1,000	Temperature as to-day
Late Glacial, duration 27,500 years	Younger 6,000	
	Middle 10,000	
	Early 11,500	Climax of Last Glaciation

Total since climax of Last Glaciation: 36,000 years

It must be emphasized, however, that only about one-third of these 36,000 years is derived from actual countings, the remainder being made up of various estimates. Of these, the reduced estimate for the Niagara Falls may be acceptable, but the assumption that 9,000 years is the length of the 'Postglacial' in North America as in Scandinavia is very daring. Bryan and Ray have recently reconsidered the problems of varve chronology in North America and rightly remarked that this figure accounts for as much as one-third to one-fourth of any of the estimates for the American ice-recession.

In view of the many pit-falls of the North American varve chronology, which are certainly well known to Antevs himself but, unfortunately, neglected by many non-experts over-anxious to obtain figures, Bryan and Ray attempted to revise the reckoning. They have introduced the following important points.

(1) The authors claim that the outer moraine on Long Island (Ronkonkoma) belongs to a *considerably* earlier glacial phase than the inner (Harbor Hill). The Last Glaciation proper, therefore, should be counted from the Harbor Hill stage only (see also p. 33), and the 2,000 years assumed for this interval by Antevs, should be dropped.

(2) The stage between Harbor Hill and Hartford (5,500 years according to Antevs) is based on countings of varve series which,

according to Bryan, are older than the last retreat of the ice. In his opinion, they cannot be used in this sequence, and he replaces them by an estimate of 2,000 years, based on the rate of recession during the following stage.[1]

(3) According to Antevs, the stages between Mattawa and Cochrane are composed of an estimated y of 3,775 years plus 2,025 years of counted varves plus 200 years (estimated) for a short re-advance of the ice at Cochrane. For this space and for the interval z, Bryan and Ray arrive at 12,350 years (Antevs, 15,000 years), estimating y at 1,000 years only and using slightly different figures for the later phases.

(4) The time u is estimated at 7,000 years both by Antevs and by Bryan and Ray. This is 9,000 years for the whole 'Postglacial' minus 2,000 for the final melting. Bryan and Ray stress that this figure is entirely arbitrary and that it constitutes a source of great uncertainty.

On the whole Bryan and Ray arrive at lower figures than Antevs does. They give 22,300 years for the age of the St. Johnsbury moraine (Antevs, 25,000), and 28,400 for the Harbor Hill moraine (Antevs, 34,500). The margin of uncertainty in both these calculations is still very great owing to the many estimates included, but they at least supply a rough idea of the periods involved.

Early man in North America. Antevs's countings and calculations (if these can be substantiated) are of importance not only from the geological point of view; they help the archaeologist to date the earliest evidence of man in North America. There has been considerable controversy among the experts in the United States as to whether man was present during the Ice Age or not. Geological and palaeontological evidence has recently been summarized by E. Howard (1935), K. Bryan (1937), and by F. Roberts (1937). Problems centre round the discovery of artefacts called Folsom points. Many of them are reminiscent of Solutrian blades, and they were found associated with bones of extinct animals. Folsom artefacts occur superficially in a wide area from southern Canada to New Mexico, but it is in the south-western United States that they were discovered in indisputable geological sections. At Folsom, New Mexico, J. D. Figgins, Barnum Brown, F. H. H. Roberts, and others found them associated with bones of a large deer and an extinct species of bison. Other sites, at Clovis and Portales, New Mexico, near the border of Texas, were studied by E. B. Howard and others. Here, evidence was brought forward for man having

[1] Bryan relies on observations of chemical weathering and solifluction in the top portion of the varved clays. It appears to me that the clays could still be of the age claimed by Antevs, if one accepts the view expressed elsewhere by Bryan, that the following St. Johnsbury stage corresponds to the Pomeranian and, therefore, was preceded by a mild oscillation. The possibility of such oscillation, by the way, introduces another unknown interval into the sequence.

been contemporary with mammoth as well as extinct bison. At Burnet Cave, in the Guadalupe Mountains, south-eastern New Mexico, Howard found a point in association with extinct bison and an extinct musk-ox like bovid, overlain by a stratum of earliest Basket-maker material. More corroborative material was discovered at the Lindenmeier site in Colorado where extinct bison and camel were found with the implements. This site has been dated by Bryan and Ray (1940) with the aid of Antevs's tentative varve chronology as falling between 10,000 and 25,000 years ago. It is slightly later than the Corral Creek substage of the Rocky Mountains glaciation, which they consider as the equivalent of the St. Johnsbury moraine of eastern North America.

Evidence is plentiful at all these sites that man had occupied North America at a time when the climate of the south-west was cooler and damper than now and when several now extinct mammals were still abundant. Antevs calls this the last pluvial phase of North America. In the basin of the Silver Lake, the end of the Mohave River, about 140 miles north-east of Los Angeles, he established that the primitive Mohave culture was contemporaneous with the overflow levels of the pluvial Lake Mohave. Since, in California, this 'pluvial' phase appears to have occurred somewhat later than the last mountain glaciation, that is according to Antevs's estimate between 25,000 and 20,000 years ago, the overflow levels in question and the enclosed culture are considered as at least 15,000 years old (Antevs, 1937). In a similar manner, Antevs determined the minimum age of the Cochise culture of Douglas in Arizona as 10,000 years. All these datings are ultimately based on the results of Antevs's varve countings in the northern part of the continent (Antevs, 1925a, b, 1928, 1931, 1932, 1934, 1936).

C. PRE-PLEISTOCENE VARVE SERIES

Varve countings in pre-Pleistocene formations. The study of annual varves is by no means restricted to the late Ice Age of Scandinavia, Finland and North America. Glacial varves comparable with those of the Last Glaciation, but infinitely older, have been reported, for instance, from the Huronian Glaciation of North America (about 7 to 800 million years ago, compare Chapter X) and the early Cambrian or Precambrian Glaciation of Australia (Coleman, 1926; about 500 million years ago), the Permo-Carboniferous Glaciations of Australia (Süssmilch, 1922) and South Africa at Nooitgedacht near Kimberley (pl. XX, fig. A; Coleman, 1926; Haughton and du Toit, 1929; du Toit, 1930; about 220 million years ago),[1] and from glacial deposits of Carboniferous age, called the Squantum Tillite and found in the neighbourhood of Boston, Massachusetts (Sayles, 1916). Proper countings have not yet been carried out in these early wit-

[1] Also known from Brazil; see pl. V, fig. A.

nesses of glacial phases. Further examples and references may be found in Antevs (1925*a*).

There are, however, laminated annual deposits which look exactly like glacial varves although they were formed under the influence of some other seasonal rhythm, such as wet and dry seasons, or alternation of chemical deposition of carbonate with biological deposition of plankton. Annual layers of this kind have been discovered and counted in various formations, and valuable results obtained for the duration of some of the earlier geological periods. Furthermore, most investigators concerned have recorded cyclic variation of the thickness of the varves (see p. 43). A few outstanding examples of varve-studies in pre-Pleistocene formations may be mentioned: [1]

(1) The Precambrian Nama Beds, South-west Africa. Age according to Radioactivity method (see p. 344) about 500 to 1,000 million years. Thickness of varves varying from 0·3–7 mm. Sunspot cycle observed (11·5 years). (See Martin and Korn, in Korn, 1938.)

(2) Shales of the upper Devonian and lower Carboniferous of Thuringia. Age according to Radioactivity method about 275 million years. Varves varying from fraction of mm. to about 10 cm. Duration of Lower Carboniferous up to middle Visée horizon about 800,000 years. Cycles very distinct and numerous, especially 11·4 years (sunspot cycle), one of 23 years, of 56·5 years, of about 21,000 years (precession of equinoxes). (See Korn, 1938.)

(3) The Carboniferous varved shales of Paterson, New South Wales (Caldenius, 1938.)

(4) The Permian anhydrite of Texas. Age according to Radioactivity method about 200 million years. Layers in the Castile formation are probably annual. Apart from other rhythms, cycles from 11 to 14 years are prominent. (See Udden, 1924.) Other Permian anhydrite and salt deposits also have been interpreted as seasonal. (See Antevs, 1925*a*.)

(5) Upper Permian anhydrite, Harz Mountains, Germany. Cycles of about 11 units observed. (See Korn, 1938.)

(6) The varved sediments of the Permian Shihhotse Series in Shansi, North China. They were formed under a tropical climate with a dry and a wet season. (See Norin, 1924.)

(7) The varved sediments in the states of Trengganu and Pahang, Malay Peninsula. They were mapped as Triassic but are possibly Upper Carboniferous. (See Fermor, 1939.)

(8) The Triassic Red Beds of Colorado. Age according to Radioactivity method about 165 million years. Sandstones with indistinct, possibly annual, layers showing cyclic variation of thickness. (See Vail, 1917.)

[1] For further references compare *Rep. Comm. Geol. Time Washington*, 1937, pp. 38–43.

(9) The middle Eocene Green River formation of Colorado, Utah and Wyoming. Age according to Radioactivity method about 50 to 60 million years. Varves of calcareous and organic mud. Cycles observed of a little less than 12 years (sunspot cycle), about 50 years, and 21,600 years (precession of equinoxes). Green River formation lasted about 5 to 8 million years. Total duration of Eocene about 23 million years. This agrees well with results of Radioactivity method (compare Chapter X). (See Bradley, 1929.)

(10) Oligocene freshwater clays, Linz on the Rhine, Germany. Cycles of about 11·5 years observed. (See Korn, 1938.)

(11) The fish shales of Glarus, Switzerland. They form part of the Oligocene Flysch formation and are marine. (See Heim, 1909, p. 331.)

(12) The laminated marls and shales of middle Sarmatian (Upper Miocene) age, found near Gleichenberg, Styria. Age according to Radioactivity method about 20 million years. Formed in a shallow sea. (See Winkler, 1913, p. 577.)

(13) The Upper Miocene marls and shales of Oeningen, near Lake Constance. Formed in freshwater lakes in a warm climate with a dry season. Lamination seasonal according to Heim, 1909, p. 331. (See also Heer, 1865, and Zeuner, 1936.)

These examples make it clear that work on varves is not restricted to glacial deposits and that a study of laminated beds of any age affords opportunities of establishing longer or shorter chronologies in years and of amplifying our knowledge of cycles. It is therefore not surprising that the same problems have been attacked in Recent and sub-Recent deposits. References to papers may be found in Bradley's excellent contribution (1929), and in Antevs, 1925*a*.

D. LONG-DISTANCE CORRELATION OF VARVE SERIES

Returning from this excursion into remote periods to the Pleistocene Ice Age it remains to be said that varve series dating either from the end of the Last Glaciation or from some earlier phase have been counted in many regions of the world apart from Fennoscandia and North America. As regards varve-sections dating from earlier phases of the Pleistocene, de Geer (1936) described some studied by Norin in the Sudeten Mountains, by Bettenstaedt south east of the Harz Mountains, and by Fraser, Trotter, and Ting in Scotland. All these are attributed to the Penultimate (Saale) Glaciation. Interesting though they are and important though they may become in the future, they cannot be linked up with definite dates at the present moment. They merely convey an idea of the time required for the formation of a certain deposit, or a phase of a glaciation, but we cannot say with certainty how many years before the present they were deposited.

The same applies to a good many countings of varve sections

which are distributed over wide parts of the world and which are supposed to be of late Pleistocene age, i.e. roughly contemporary with the retreat of the last ice-sheet from Germany to the mountains of Scandinavia. Those from countries outside Scandinavia and eastern U.S.A. and Canada, are contained in the following list :

European Alps (de Geer, 1932*b*; 1940, p. 227, pl. 90). About 25 localities, no details published.

Scotland (de Geer, 1935*c*, 1935*d*). At Dunning on the River Earn, south-west of Perth, 59 varves were counted. De Geer compared them with a series from Lyngby, near Copenhagen and dated them as from — 4313 to — 4371 of the Swedish scale, or early Gotiglacial.

Ireland (Charlesworth, 1939). One hundred and twenty years counted at the Silent River reservoir and at Martin's brick-pit, Belfast. Summer and winter layers distinct.

Iceland (H. Wadell, in E. H. de Geer, 1928).

Poland (Halicki, 1932; Krygowski, 1934; de Geer, 1935).

Estonia (*teste* de Geer, 1940).

Russia (Schostakowitsch [1], Perfiliev [2], de Geer, 1940, p. 232, pl. 90).

North-western Himalaya (Norin, 1925, 1926, 1927).

New Foundland (Lundberg, 1929).

Southern Chile (Caldenius, in de Geer, 1929).

Argentina (Caldenius, 1932, and in E. H. de Geer, 1927, 1934).

New Zealand (Caldenius, in de Geer, 1940, p. 225, pl. 90).

East Africa (Nilsson in de Geer, 1934*b*). See Zeuner, 1944, p. 211

Teleconnexions. Readers, however, who study some of the papers enumerated in this list, will notice that the authors, and especially de Geer himself, hold a more positive view than that expressed above, and consider themselves justified in dating varve-series found, for instance, in South America directly on the Swedish time-scale. The agreement of the annual variations in varve-thickness is claimed to be good enough for the purpose of direct correlation (de Geer, 1940, p. 35). Similarly de Geer (1926, 1935*b*) correlated varve-series obtained in North America with those of his home country, dating the former in years on the basis of the Swedish time-scale. To this practice of correlating varve-series over wide distances de Geer applies the term *teleconnexion* (see also p. 15). It is natural that the agreement of series from distant localities is less good than that of series from neighbouring localities, and similarities therefore are less easily detected. For this reason, de Geer employs the method of the 'biennial maxima' described on p. 25 in order to simplify the curves and discover correlatable sequences. He is

[1] Reference not traced.

[2] Reference to results not traced. Preliminary announcement, Perfiliev and Chernov (1939).

satisfied that, in this way, varve series of North America, South America, the Himalayas, East Africa, and Iceland, can be correlated with, and dated in years by means of, the Swedish standard time-scale (fig. 11). It would indeed be a great help if this procedure were reliable.

But quite apart from the question of whether the Swedish time-

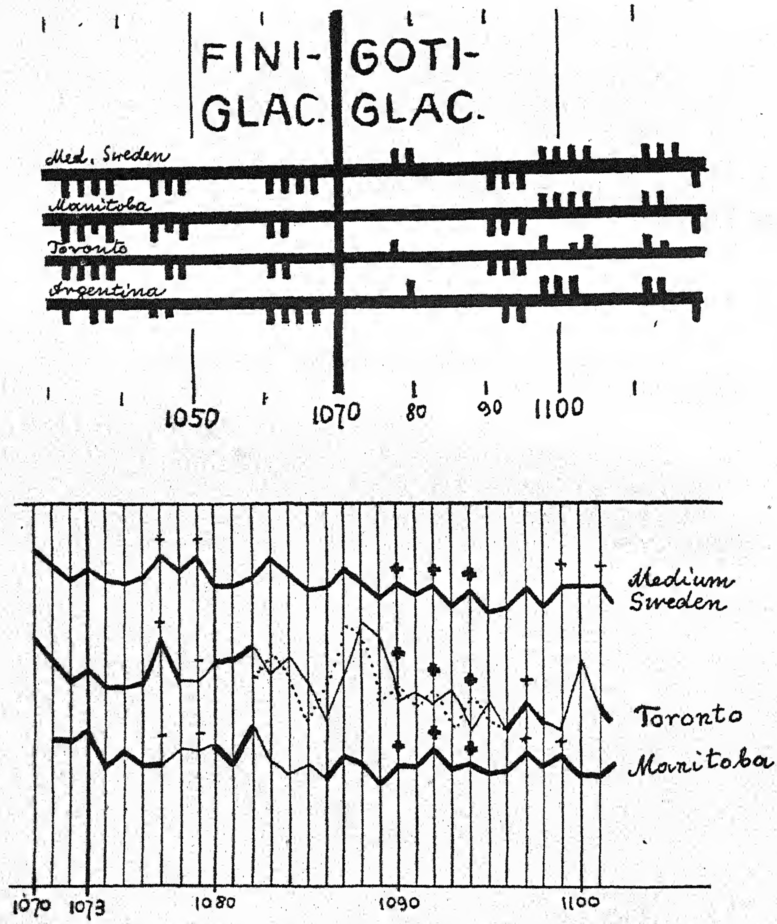


FIG. 11.—Plots of biennial maxima (above) and a varve diagram, illustrating de Geer's practice of 'teleconnexion'. The lower diagram shows several of de Geer's symbols (thick line, thin line, heavy cross, thin cross, minus sign for absent biennial maxima, &c., which are not always placed where one might expect to find them). The dotted line in the Toronto curve indicates a parcel of measurements shifted so as to agree more closely with the lower curve, on the assumption that a varve is missing.

The upper diagram shows series of biennial maxima, including the section of the time-scale shown in the lower diagram, for Sweden (average curve), Manitoba and Toronto in Canada, and Argentina.—After de Geer, 1934.

scale can be regarded as final or not, serious objections have been raised against teleconnexions. Antevs in particular denies that teleconnexions are possible on the available evidence (1935). He says that the greater the distance between two localities the greater has to be the degree of accuracy required for the agreement of the curves, and expresses his view in the following words (slightly shortened):

> The relative thickness of the varves primarily records the summer weather: thick varves signify warm, clear, and long summers; thin varves denote cool, short, and foggy summers. However, the varves are not perfect records of the weather summer after summer, for the deposition of the clay and the thickness of the laminae were influenced frequently by other local conditions. Graphs from adjacent localities, however, usually match well. Those derived from widely separated localities in the same large lake, or from different lakes in the same limited region, normally show a less detailed, yet good agreement. Correspondence among curves diminishes, as the conditions of climate, ice wastage, and clay deposition diverge, and as the supply of meltwater and glacier mud changes. Finally, stages are reached when a considered correlation on the conformity among the curves is doubtful, or when no correlation can be made. The correlator himself decides when these border stages are reached. His responsibility is the greater, as the degree of correspondence that is needed to establish a correlation is reversed to the probable conformity of the graphs. Curves of adjacent clay deposits which were formed under similar conditions and which by striae, moraines, etc., are known to have been deposited at the same time may be correlated on much smaller resemblance than curves from widely separated regions. In other words, the more remote the clay localities, the greater conformity in the details of the curves is imperative.

Antevs further shows that de Geer uses the term 'biennial maximum' in a very wide sense and that thereby agreement is sometimes introduced in the curves where other investigators would hardly be inclined to admit it. The results of studies in teleconnexion, therefore, largely depend on the worker's inclination to find resemblances in the curves under consideration (fig. 12), and it is evident that correlations from continent to continent cannot, at present, be regarded as satisfactory. As yet, 'tele-dating' by means of varves can hardly be carried out successfully.

There is another important point concerning teleconnexion. The method implies that the summer-weather suffered the same or similar fluctuations in widely distant regions, since the thickness of the varves depends on the melting effects of summer-heat. Meteorological observations have not yet proved such parallelism of weather conditions between continents, and it is significant that whilst papers have been written which were intended to demonstrate parallelism of weather development in North America and Europe, other papers undertake to prove the contrary, i.e., an alternation

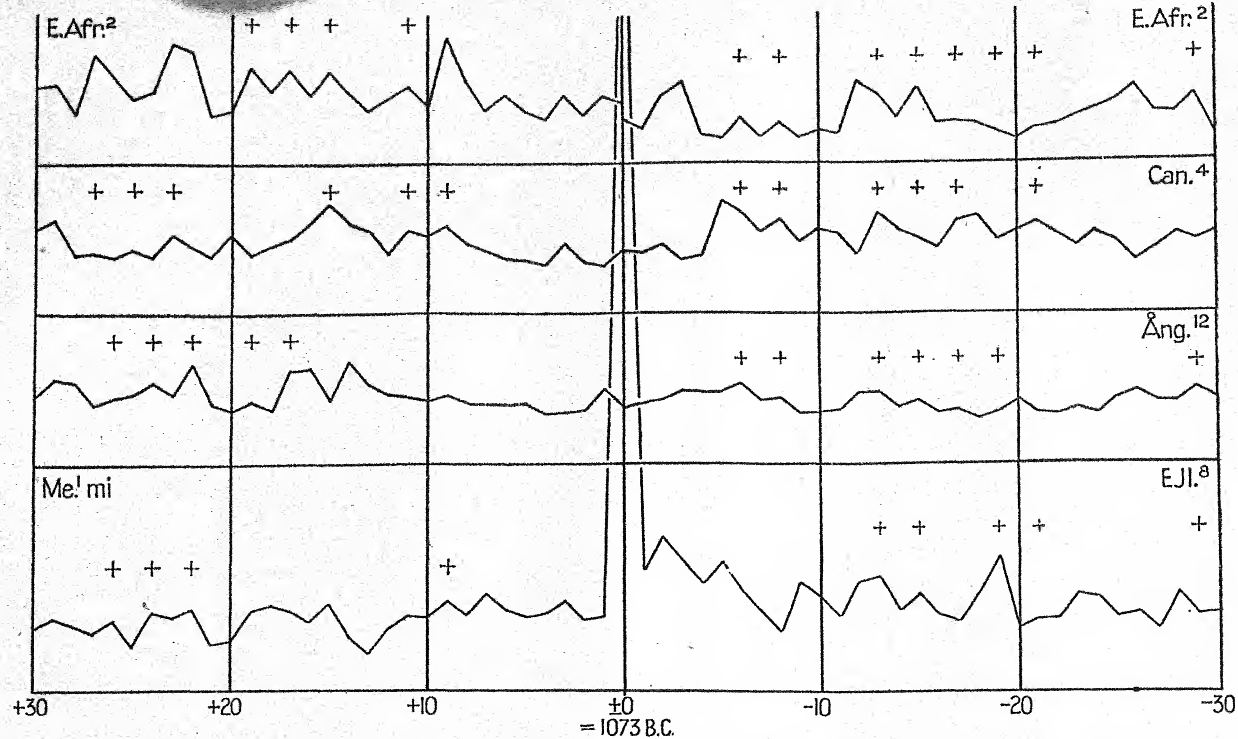


FIG. 12.—Four sections of varve diagrams, dated and 'teleconnected' by de Geer. All symbols omitted, except crosses for those biennial maxima which were marked by the author.
Me¹mi. Very thin varves ('micro-varves') from Indal, Sweden, including the Zero drainage varve.
E Jl.⁸. From Döviken in the Ragunda valley, beginning with the zero varve.
Ång. 12. Ångerman River valley.
Can. 4. Haileybury, Timiskaming, Canada.
E. Afr.² Laminated lake deposits, East Africa.
Except for very short stretches, the curves do not resemble each other, yet de Geer considered them as sufficiently similar for correlation.—After de Geer (1940, pls. 75, 76).

(for Greenland and Europe, Loewe, 1937). Further meteorological research of this kind is an essential preliminary to teleconnexion of varve-series.

E. CYCLES IN VARVE SERIES

Cycle analysis. Before proceeding to the application of varve chronology to peat sections, raised sea-levels and, above all, human industries in Europe, the cycle phenomenon has to be considered. As in the case of tree-ring records, the variation in thickness of the annual layers in varve sections is often to a certain extent periodical, groups of particularly thick or thin laminae appearing at more or less regular intervals. The average period of these cycles can be investigated by certain methods,[1] and the periodicities discovered in this way may then be interpreted. The most striking of all is that which equals, or approaches the sunspot cycle (11·4 years). As explained in the first chapter, it is frequently observed in tree-ring records. In varved deposits, however, it is decidedly rare. Antevs (1929*a*) says that ' perhaps the most important result so far obtained from the analyses of the varve curves is the almost complete absence of the 11-year cycle in the curves studied by C. E. P. Brooks. The nearest approach to an 11-year periodicity is one of 10·4 years in a varve series from Argentina, but even this has nothing of the compelling rhythm of the modern sunspot curve.' Subsequently it became apparent that in phases with weak sunspots the 11-year cycle is often absent, and Antevs, Brooks, Douglass, Glock, and Reeds now agree that, instead, a 10-year cycle is more frequently observed in glacial varves (fig. 13). This is sometimes called the ' dearth-cycle '. Its presence in tree-ring records of the seventeenth and eighteenth centuries was mentioned in the first chapter (p. 18), and it was found that during the same time the cycle of sunspots apparently was reduced to an average of 10·2 years (Douglass, 1936). Moreover, Antevs (1929*b*) claims that the glaciers of western Norway expanded between the end of the seventeenth and the middle of the eighteenth century. Douglass, who analysed for cycles Antevs's varve-measurements from the Connecticut Valley (Douglass, 1933), found in some 4,000 years of varve-records only two good examples of the 11-year cycle, covering not more than about 400 years. All this suggests that the weakness or absence of the 11-year sunspot cycle, and the presence instead of the 10-year dearth cycle may have something to do with deterioration of climate and with the increase of glaciers. One cannot state yet what the connecting factor actually is, though it is known that fluctuations of solar radiation are associated with sunspot fluctuations (p. 17). Several authorities therefore have suggested that fluctuations of solar radia-

[1] A. E. Douglass has spent much time on designing and improving such methods. See bibliography of Chapter I, Douglass, 1936.

tion, among other factors, are figured in the varve records. De Geer even goes so far as to call his varve plots 'solar curves', thus replacing in the term the observed phenomenon by one of its possible causes.

Various other cycles have been observed in varve records. Some of them, as those of 23 and 56 years, are reminiscent of similar cycles detected by meteorologists. A few of these cycles are referred to in the list of pre-Pleistocene varve deposits on p. 37, and others are mentioned in the reports on the second conference on cycles (see Antevs, 1929*a*, *b*). There is however one very long cycle which

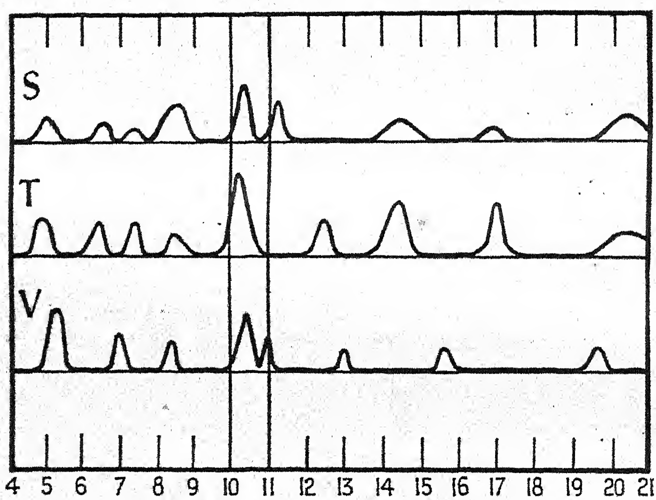


FIG. 13.—The 10-year dearth-cycle appearing in sunspots (S), tree-rings (T) and varves (V) from North America. These are not actual plots but diagrams showing the average frequency of cycles in a large number of plots. A cycle of just over 10 years stands out strikingly in all three diagrams, but otherwise the varve diagram contains cycles which differ appreciably from those of the other two.—After Douglass (1933) and Glock (1937).

needs to be discussed here, namely that of about 21,000 years. It has been observed in varved deposits by Bradley (1929) in the middle Eocene of the United States and by Korn (1938) in the lower Carboniferous of Germany. Furthermore, G. K. Gilbert (1895), who studied the regular alternation of limestone and shales in the upper Cretaceous of Colorado, came to the conclusion that this was caused by the astronomical rhythm known as the precession of the equinoxes the the duration of which is about 21,000 years (see p. 136). It is, in fact, most surprising to find the same rhythm in varve shales of two other geological periods, and there confirmed by an actual counting of the annual layers. It will be shown later on that the precession

of the equinoxes had an important influence on the development of glacial and interglacial phases during the Pleistocene, and Bradley's and Korn's findings are extremely valuable evidence confirming the correctness of the astronomical chronology of the Pleistocene Ice Age and its human industries, which will be expounded in chapters V to IX.

The discovery of cycles of this kind has yet another bearing on our dating work. It shows that the length of the astronomical year has not altered, at least since the beginning of the Carboniferous. Otherwise, the shorter of the cycles observed could not agree so perfectly with corresponding cycles observed at the present day.

Summary. Summarizing briefly the results so far obtained by varve analysis the following points must be regarded as important.

(1) De Geer's method of analysing series of annual laminated deposits has provided a considerable number of shorter or longer time-scales in years, chiefly of late Pleistocene age.

(2) The most complete is that of the late Glacial and Postglacial of the Baltic region. It covers about 15,000 years and is linked up with the modern historical calendar.

(3) In North America a corresponding though less complete calendar has been worked out and suggestions regarding the age of man in America have been based on it.

(4) Cycle analysis has detected in varved deposits the sunspot cycle and that of the precession of the equinoxes among others, and thus provided evidence for solar influence on climatic fluctuations.

(5) It is necessary, however, to emphasize that the accuracy expressed by the use of exact dates A.D. and B.C. is largely fictitious. Whether the Baltic Ice Lake was drained in $-1073 = 7912$ B.C., is doubtful, but it is most convenient to accept some such date to construct the time-scale on. De Geer himself has frequently used round figures instead of accurate dates. The time-scale used in the present book hinges on Lidén's work on the Ångerman River and on de Geer's latest pronouncements and corrections of earlier datings.

A further source of uncertainty lies in the correlation of the varve-curves themselves. A glance at figs. 7 or 12 will show that the resemblance of the correlated sections sometimes leaves much to be desired, especially with regard to sections from different continents.

But it must be admitted that the general results of de Geer's chronology agree reasonably well with those obtained in Finland and with the estimates obtained by different and independent methods. Thus, the time-scale based on varve-countings appears in fact to give us at least an approximate chronology of the geological events in the Baltic area since the Last Glaciation.

CHAPTER III

APPLICATIONS OF VARVE ANALYSIS IN THE DATING OF PEAT-BEDS, AND ANCIENT BEACHES OF LAKES AND SEAS, CONTAINING HUMAN REMAINS AND IMPLEMENTS

Introduction. As in other geological dating work so in the chronology of the Postglacial and late Glacial, an intermediary 'relative chronology' is required which places the various human industries in relation to climatic or other geological phases established by geological evidence. As usual, the correlation of the archaeological finds with climatic phases has been the dominant subject of study, and the number of cases in which the absolute time-scale can be applied is decidedly small. These cases, however, serve as fixed points and therefore are important. Generally speaking, two ways are available for linking up prehistoric finds and varve-countings. The first applies to finds made in Fennoscandia on raised beaches which represent certain phases in the evolution of the Baltic Sea which, in turn, can be correlated with varve-sections. The other relies on finds made in peat or other organic or semi-organic sediments. The climatic phase during which these layers were formed is often determinable by means of botanical investigation, and, since the climatic development of the late Glacial and Postglacial depended on the recession of the ice, connexions with the phases of the Baltic, with certain moraines, or even with sections of varved clay, may be established. It is evident that, in this manner, varve dates can be linked up with certain events in climatic history and therefore with certain archaeological horizons, but owing to the several intermediaries the dating work is bound to progress slowly, and the results are usually reliable within certain limits only. Inaccuracy is introduced by the drawbacks of varve-counting itself (with its chances of missing varves and of counting the same series twice in different sections), by the difficulty of correlating sea-levels with the varves, the possibility of a time-gap between beach-formation and human occupation, the possibility of objects in peat-sections sinking through soft layers or being otherwise dislocated, and other factors. It is therefore not surprising that the calendars proposed by various workers do not agree entirely and are regarded as tentative by the authors themselves. As research goes on, however, evidence accumulates, and though the individual results may not be entirely satisfactory, if taken together they do afford information regarding the time during which a cultural phase was at its climax. T. Nilsson (1935) has demonstrated this for Scania (fig. 25), where the majority of finds belonging to some cultural phase are concentrated in certain levels of the peat sections.

From the Bronze Age onwards indirect historic dating greatly predominates over geological dating, and an unfortunate tendency of dating geological horizons by means of archaeological finds is sometimes observed.

Before reviewing some of the important localities a few more words have to be said about the two chief 'intermediaries', namely the raised beaches and the pollen-contents of peat-sections.

A. RAISED BEACHES OF THE BALTIC

The two causes of changes in area and geographical position of the Baltic are (1) the *eustatic* rise of sea-level and (2) the *isostatic* uplift of Fennoscandia.

Eustasy. (1) As the ice was melting at the end of the Last Glaciation, a large quantity of water, hitherto stored in the form of ice, returned to the ocean. The general water-level was thus made to rise gradually. Correspondingly, when a glaciation began, much water was absorbed in forming the ice-caps, and the sea-level fell. Such movements of the sea-level are called *eustatic,* and the phenomenon, *glacial eustasy.*

Isostasy. (2) On the other hand, as the process of melting went on over Fennoscandia towards the end of the Last Glaciation, the earth's crust in this particular area was gradually released from the considerable weight of the ice-cap. Under this weight, Fennoscandia had been elastically depressed during the glaciation and, as the ice was waning, the region responded and gradually rose again. It did so much more in the central parts than near the periphery (fig. 14). This 'isostatic' reaction, which still continues, inevitably influenced the geographical position of the Baltic Sea. In the early stages, when Scandinavia was deeply depressed, the Baltic covered a large portion of southern and middle Sweden, but as this zone emerged, the Baltic tended to spread southwards. At the same time (and this is the main point in connexion with dating) the beach-lines of the earlier phases were lifted up in Fennoscandia, and the more so the nearer they were to the centre of the uplifted region. The fossil shore-lines, therefore, of the Ice Lake, Yoldia Sea, and other stages of the Baltic now are no longer horizontal as they certainly were when the sea was building them. Instead, they rise northwards or inland as shown in fig. 15. This fact enabled workers in Finland and Scandinavia to reconstruct the development of the Baltic basin in great detail (Sauramo, 1939 [1]).

Thus, the entire history of the Baltic can be interpreted as the result of the interplay of isostasy and eustasy.

Raised beaches of the Baltic. Baltic Ice Lake. In the region surrounding the waning ice-sheet of Fennoscandia a series of raised

[1] Numerous earlier papers on the subject, by Ramsay, Bergehell, Sederholm, &c., will be found in the *Bull. Comm. géol. Finlande.*

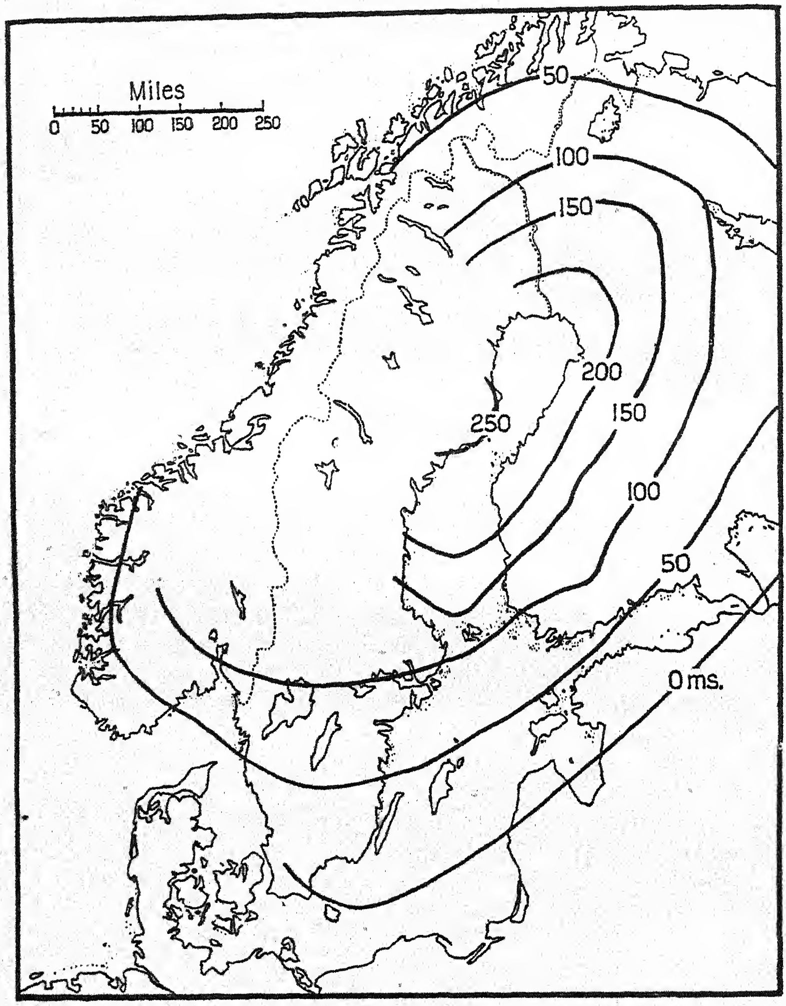


FIG. 14.—Map of the Baltic Region showing the isostatic rising of the beach of the first Rhabdonema Stage (Rha I) since about 6800 B.C. The centre of upheaval is a small area on the west coast of the Bothnian Gulf where this shoreline has by now risen to 250 metres above the sea-level. The amount of uplift decreases radially, and from Lake Ladoga through the Gulf of Riga to south Scania runs the hingeline along which the ancient beach has retained its original height. South of this line no movement, or even submergence, has taken place.—After Sauramo (1939).

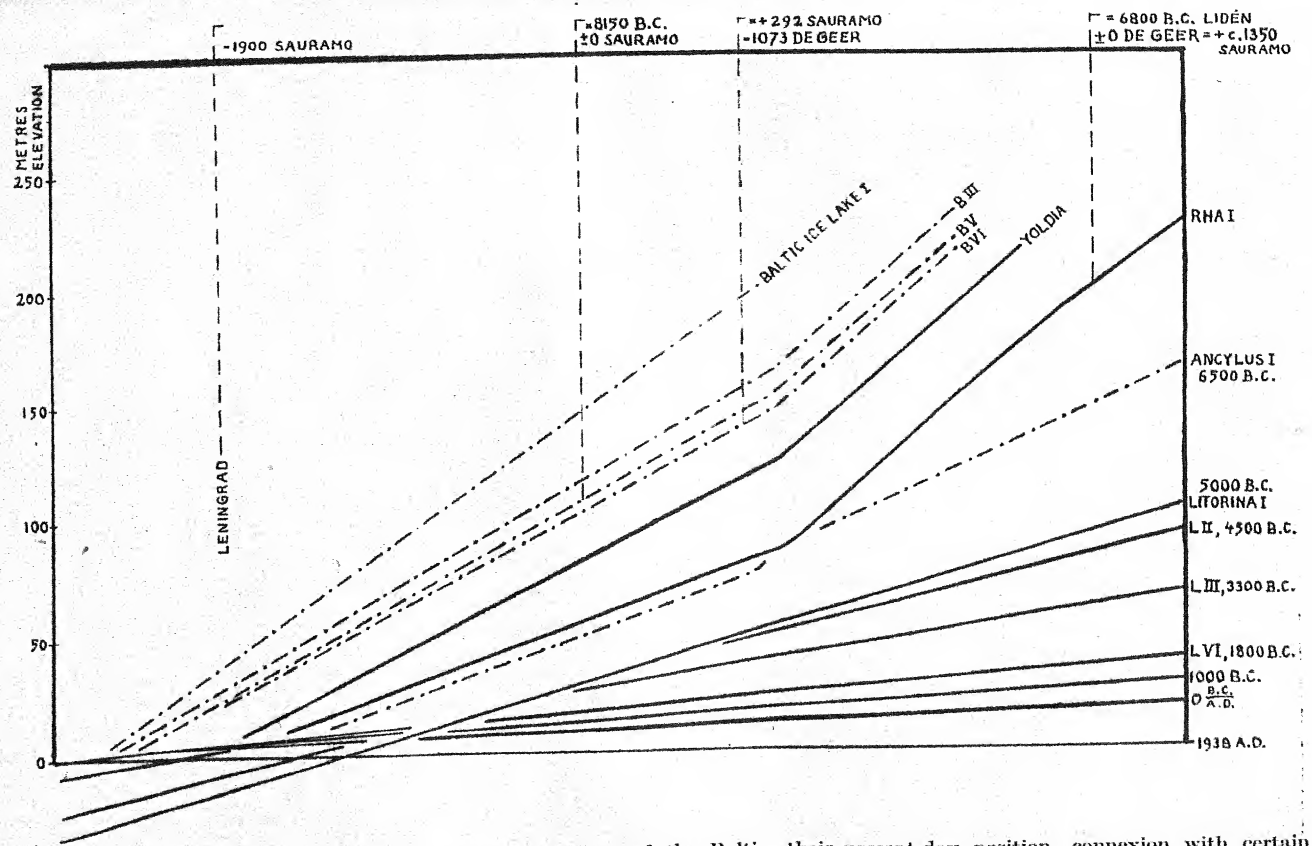


FIG. 15.—Diagram of the most important shore-lines of the Baltic, their present-day position, connexion with certain moraines, and dates based on varve countings. The older a shore-line, the greater its uplift. The uplift is increased also towards the centre of upheaval (on right of diagram, see fig. 14). ± 0 in Sauramo's chronology represents the second Salpausselkä Moraine in Finland. It is associated with Stage V of the Baltic Ice-Lake. ± 0 in de Geer's chronology represents the Central Swedish Moraine. It is associated with Stage VI of the Baltic Ice-Lake, and 292 years later than Sauramo's zero point.—Simplified, after Sauramo (1939).

FIGS. 16–19.—Four stages in the development of the Baltic Sea.

FIG. 16.—The Baltic Ice-Lake at about 8800 B.C. Water escapes through the Billingen Gap. Climate of the ice-free region subarctic (Younger Dryas Time). This is the geographical background of early Mesolithic man (Ahrendsburg, Lyngby, &c., cultures).

beaches was formed in late Glacial and Postglacial times.[1] During the maximum of the Last Glaciation the depression which is now filled by the Baltic Sea was entirely covered with ice, but when the ice-margin had retreated to some extent, a lake was formed which was supplied with meltwater and not yet connected with

[1] The same applies to the North American ice-sheets (pl. VI, figs. A, B).

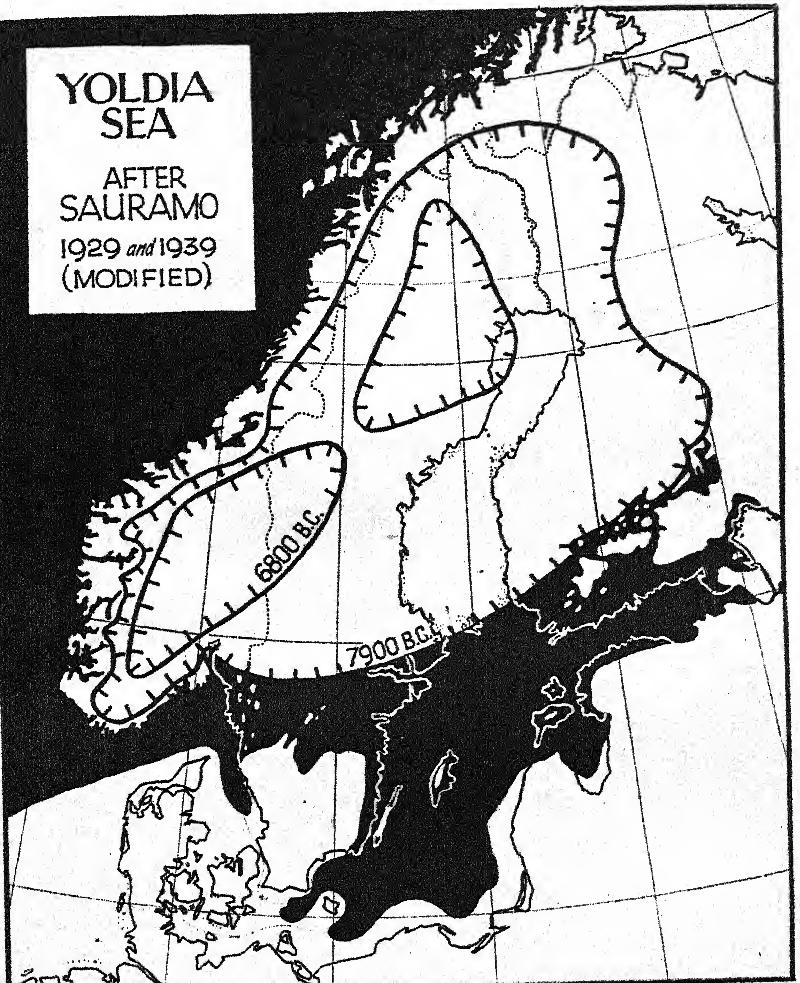


FIG. 17.—The Yoldia Sea at about 7900 B.C. South Scania connected with Denmark. Wide connexion with the North Sea. By about 6800 B.C., the ice had melted away to form two small separate areas (' bipartition ' = de Geer's zero point), and the Bothnian Gulf had become part of the Baltic. This later phase is the ' First Rhabdonema Stage '. Climate of the ice-free region subarctic to Preboreal. This is the geographical background of late Mesolithic man (Maglemose culture).

the ocean except by an overflow. This earliest phase is termed the *Baltic Ice Lake* (fig. 16); it ended when the ice had receded sufficiently to free the Billingen Gap in southern Sweden. This event was connected with the retreat from the Central Swedish Moraine, and it produced a sudden lowering of the Ice Lake level by about 28 metres (year — 1073 of de Geer's chronology, p. 28).

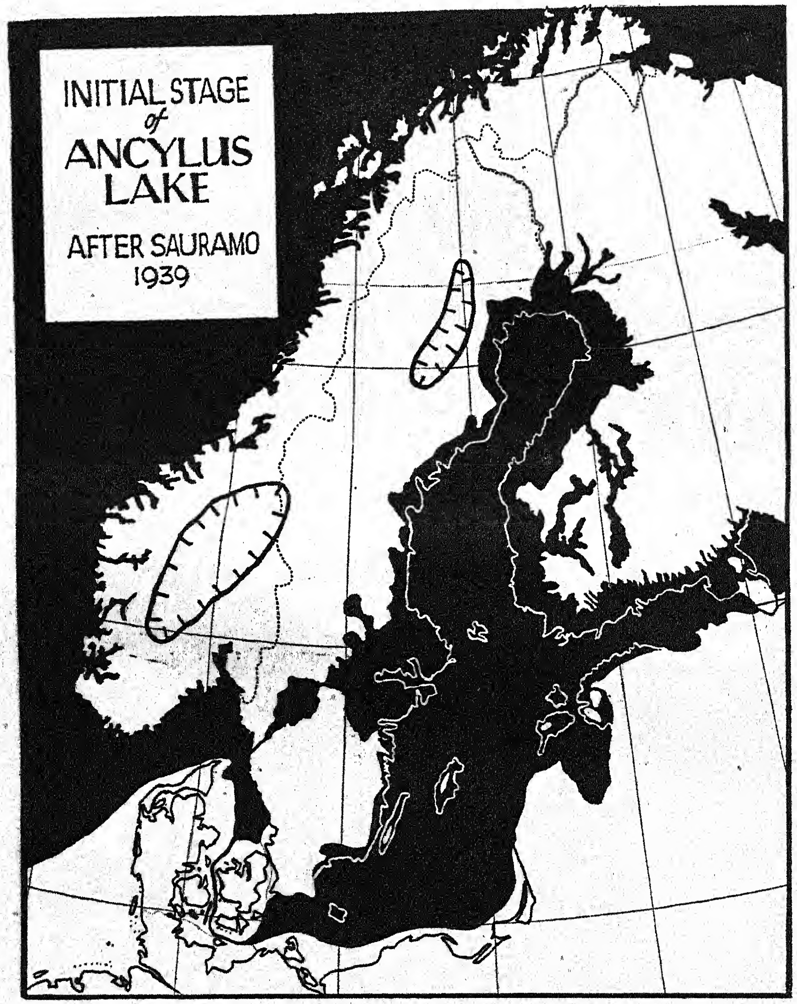


FIG. 18.—The Ancylus Lake at about 6500 B.C., drained by Svea River and Närke Sound. Climate Boreal. Maglemose culture continuing.

Yoldia Sea. Saltwater now entered the Baltic,[1] but owing to the presence of ice along its northern shores the temperature was still low, and arctic and subarctic shells lived in the water. Among them was the genus *Yoldia* after which this stage is called the *Yoldia Sea* (fig. 17).

Ancylus Lake. These conditions did not prevail for long, and in consequence of the isostatic upheaval of Scandinavia temporarily

[1] The complicated oscillations established by Sauramo (1934, 1939) are omitted here. See also Wright (1937, pp. 354–8).

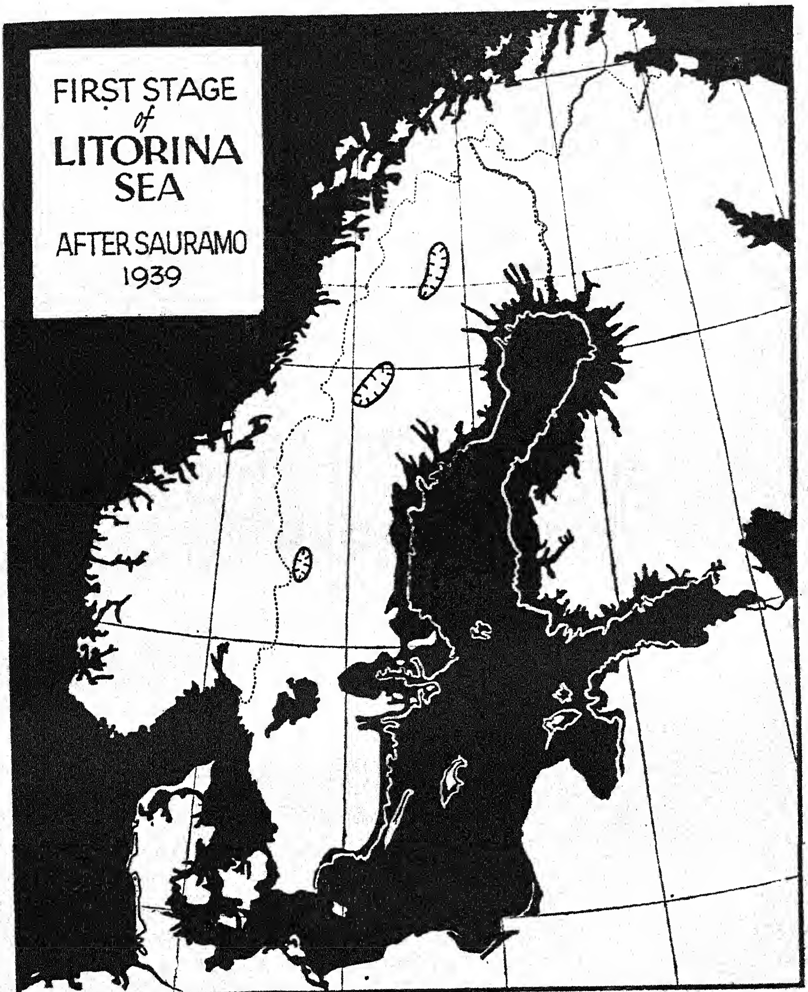


FIG. 19.—The first stage of the Litorina Sea, at about 5000 B.C. Connexion with the North Sea through the Danish Sounds as to-day. Climate Atlantic. At this time, Neolithic man made his appearance, with the Ertebölle or Kitchen-midden Culture.—Since then, a regression of the Baltic has taken place, chiefly in the north and largely in connexion with the isostatic rising of Fennoscandia.

proceeding at a faster rate than the eustatic rise in sea-level, the Baltic once more became separated from the ocean, forming a lake with its surface about 30 metres above the present sea-level and with an outlet along the Svea River (von Post, 1928). After a typical genus of mollusca this second freshwater phase is termed the *Ancylus Lake* (fig. 18).

Litorina Sea. Later on, as the rise of the land slowed down

relative to the rise of sea-level, an open connexion was re-established with the North Sea, this time no longer across southern Sweden, but through the Danish Sounds only, whilst the southern (north German) coasts were partly submerged. This is the *Litorina Sea* (fig. 19) with the *Litorina transgression*, named after the Common Periwinkle (*Litorina littorea* L.).

The interference of this eustatic rise of the sea with the isostatic rise of the land had the result that the maximum of the transgression (which produced the highest Litorina beach-line) occurred at different times in different areas. In the north (e.g. in Finland), where the isostatic rise was rapid, the first Litorina beach represents the maximum of the transgression; it has since been raised to a considerable height, at a rate which was greater than that of the rise of the sea-level.

In the south, however (e.g. in Denmark), the rise of the land (if any) was slower than that of the sea, so that the sea gained on the land until the eustatic maximum of the transgression was reached. Here, the highest Litorina beach is therefore the latest.

The 'Litorina maximum' has, in the past, often been regarded as an event which proved contemporaneity all over the Baltic. That this is not so has been established only recently (Troels-Smith, 1937; Iversen, 1937; Childe, 1943). This introduces a serious handicap into the exact dating of archaeological sites relative to the Litorina phase.

Limnaea and Mya phases. The present-day beach-line is, as a rule, below the highest Litorina level everywhere around the Baltic. Since the outlines of the present Baltic were established by the Litorina transgression, one might say that this stage still continues. Actually, its later sub-stages have received special names, *Limnaea* phase, and *Mya* phase, respectively.

This, in a very few words, is the story of the Baltic Sea. Detailed research has revealed a great many complications and the actual course of events was not so simple as outlined above. For our purpose, however, it is unnecessary to discuss details. Those interested in the matter may be referred to Sauramo's latest work on the subject (1939).

Prehistoric sites on ancient beaches. Many phases of the Baltic are closely connected with deposits of varved clay formed in the neighbourhood of the ice-margin which, for a considerable time, itself formed the northern shore of the sea. Moreover, Sauramo and de Geer found that changes of salinity, as they occurred for instance when the Ice Lake was replaced by the Yoldia Sea, left their traces in the varved clays. For these reasons certain ancient shore-lines could be dated in years (compare fig. 15). On the other hand some of the prehistoric sites, especially those of the kitchen midden culture (early Neolithic) are situated on certain ancient

beaches and their industries have not been found below the height of sea-level corresponding to these beaches. The example of the Esbo and Kyrkslätt district in southern Finland (fig. 20) is clear enough. Here, kitchen midden dwelling sites are almost entirely restricted to the shoreline indicating the highest level of the Litorina Sea at an altitude of 34 metres. Elsewhere, this sea-level has been

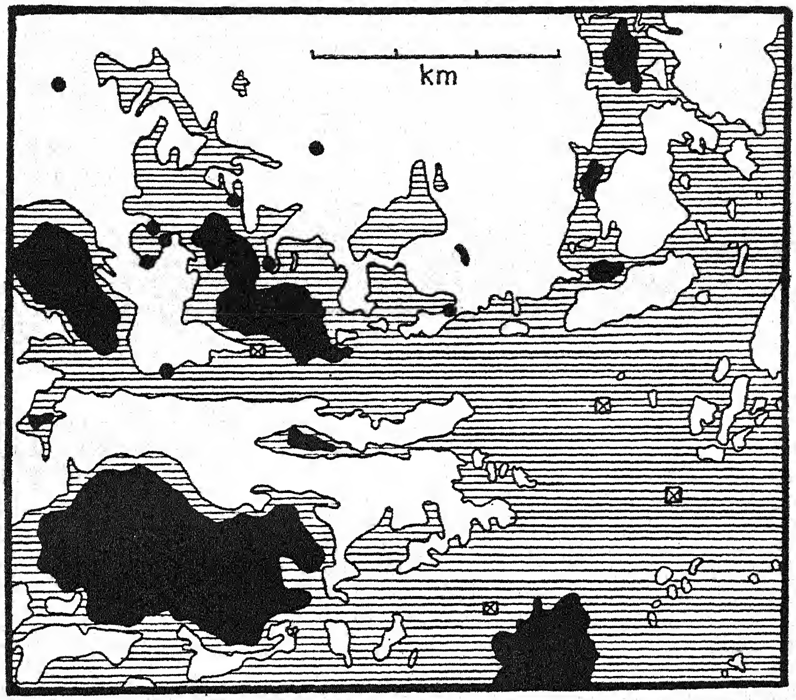


FIG. 20.—The dwelling places of the Kitchen-midden Culture in the district of Esbo and Kirkslätt in south Finland, in relation to the beach-line of the maximum transgression of the Litorina Sea.

White : Land during the Litorina phase.
Black : Water at the present day.
Hatched : Areas submerged during the Litorina Phase.
Black circles : Kitchen-midden sites.
Squares : Present-day settlements.

The association of the Kitchen-midden Culture with the beach-line of the Litorina Sea is evident.—After Europaeus, and Sauramo, 1929.

correlated with varves and dated in years. It is in this indirect way that a number of prehistoric industries in the Baltic region and on the west coast of Scandinavia have been dated. Results thus obtained will be described later on, after an outline has been given of the second important intermediary method required to establish a late Glacial and Postglacial chronology.

B. BOTANICAL METHODS AND CLIMATIC PHASES

This other line of research is almost entirely botanical and based on the lake and peat deposits which have accumulated since the ice receded from the area under investigation. In a few important cases such deposits were found resting on varved clays or on raised beaches, or they could be safely connected with either of these or with moraines. The results of varve countings, therefore, could be applied and approximate dates in years obtained for the deposits as well as for any enclosed prehistoric industries.

Lake deposits and peats. The lake deposits and peats are studied in the first instance in order to reconstruct the plant associations which, in turn, indicate certain climatic conditions. The deposits in question may be classified as follows (based on Gams, and Godwin, 1938):

I. Freshwater deposits:

Gravel, Sand, Clay: chiefly deposited from moving water, with little or no action of organisms.

Marl: clay with a large amount of calcium carbonate which sometimes is of organic origin.

Nekron mud (gyttja, sapropel): chiefly organic lake deposits derived from plankton and other organisms.

Gel mud (dy): colloidal humic material often derived from peat bogs, carried in solution by the water, and precipitated.

II. Peats growing under or at the water level:

Phragmites peat (peat formed by the Common Reed and similar plants growing in shallow water).

Equisetum (horse-tail) peat and other varieties.

III. Peats growing above the water level:

Sphagnum peat (moss peat).
Calluna peat (heather peat).
Pine-bog peat.
Brushwood peat.
Grass-bog peat.
Eriophorum peat (Cotton-grass peat).

Of these sediments by far the most important are the various kinds of peat.[1] The second in importance are the nekron muds. Plant remains are, as a rule, abundant, especially the minute grains of wind-transported pollen caught on the wet surface of the bog or the water itself. Remains of leaves and seeds also are found frequently. In addition, diatoms, remains of insects, fishes, &c., may be observed, but it is the contents of tree pollen that afford the real basis for a climatic analysis of the deposit.

[1] A useful summary on peats, by Fraser (1943), has appeared recently.

Macroscopical plant-remains. The coarser remains of plants contained in the sample are washed out and examined macroscopically or under a low-power microscope, and seeds and leaf-remains are determined. Before the time of pollen-analysis this was the only method used. It was brought to high perfection by Clement Reid in his studies on the Pleistocene flora of Britain, and by Blytt and Sernander in Scandinavia.

Technique of pollen-analysis. In the finer material, fossil pollen-grains occur, having been brought in large numbers by wind. The pollen-contents of a peat are more or less characteristic of the tree-associations that grew in the neighbourhood of the spot under investigation, and it is therefore worth while to submit them to a close examination. This method, developed chiefly by Lennart von Post and now used very widely in many countries, is called *pollen-analysis.*

For the analysis a small quantity of the material is treated with sodium or potassium hydroxide or some other dissolving agent which removes most of the organic matter but leaves the pollen which is extremely resistant. Centrifuging is often useful to separate the light pollen from the heavier grains of inorganic matter. The pollen is then studied under a microscope, the grains of each genus or species present are counted and the percentages of frequency calculated.

Representation of results. In tabulating the result many authors exclude the hazel (*Corylus avellana*) from the total of 100 per cent. and instead add it as a supernumerary component, as shown in the following instance:

Depth (cm.)	Pine	Spruce	Alder	Birch	Willow	Mixed Oak Forest	Hazel
(I) 85	6·7	74·0	10·0	4·4	—	4·7	15·3
(H) 100	17·3	62·7	5·3	3·3	—	11·3	4·7
(G) 115	8·7	58·7	18·0	5·3	—	9·4	12·7
(F) 130	12·0	58·5	13·5	4·5	0·5	11·0	35·5
(E) 145	54·4	32·2	3·9	2·4	0·5	6·0	12·2
(D) 160	84·0	12·7	1·3	2·0	—	—	8·7
(C) 175	83·5	2·5	1·0	8·5	3·5	0·5	3·0
(B) 190	74·5	1·0	—	12·5	12·0	—	1·0
(A) 205	95·0	—	—	4·5	0·5	—	—

Table showing the pollen-contents of the Weisswasser bog, Glatzer Schneegebirge, Sudeten Mountains. From L. Stark, *Bot. Jahrb.*, vol. 67, 1936.—Illustrates the method of excluding the hazel from the total of 100 per cent. It also shows the early Postglacial development of vegetation in Central Europe, from a pine-phase (A), pine-birch-phase (B), hazel-phase (F), to the mixed-oak-forest (H). Superimposed on this development is the immigration of the spruce, a tree preferring a continental climate and typical of mountainous regions in Central Europe. This bog is 830 metres above sea-level.

The reason for this procedure is that hazel produces pollen in great abundance. It therefore tends to dominate in samples derived from spots close to which one or a few hazel-shrubs were growing, and

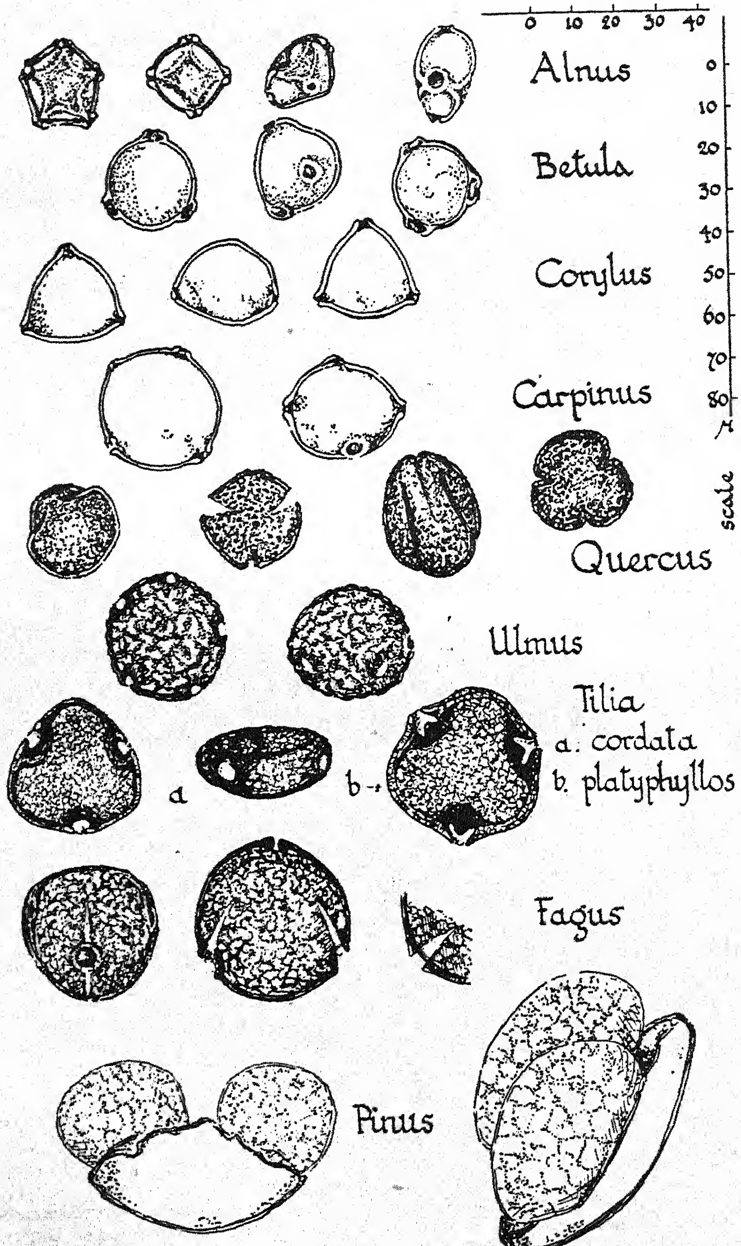


FIG. 21.—Pollen-grains of the more important trees as found in Postglacial deposits. From Godwin (1934), with permission.

its frequency cannot always be regarded as representative of the frequency of the species in the plant association. To a lesser degree the same applies to other species also, and this is why some workers prefer to treat all groups on an equal footing. Only where pollen of grass and herbaceous plants are included in the diagram, is it usual to add these as a surplus to 100 per cent.

One of the principal aims of pollen-analysis is to study the *changes* in the composition of the tree- or forest-flora. It is therefore most essential to investigate complete sections from which samples are taken at close intervals. A single sample cannot show the alterations in the composition of the flora in the course of time, though in well-investigated districts a trace of peat on an implement that has been kept in a collection for many years, may be sufficient to identify the level from which it came (compare Nilsson, 1935).

The results of pollen-analyses are often given in the form of diagrams rather than in tables (compare von Post, 1929*b*). Certain symbols are used for the various kinds of pollen, as for instance in fig. 31. This mode of representation is the most often applied. The use of a large number of symbols is avoided in another kind of diagram which shows each species separately. Naturally, the scale is smaller, but the changes stand out very clearly (fig. 33). For use on maps, circles are the appropriate means of demonstration. A circle with sectors giving the frequency of the most important species in the local pollen-spectrum can be inserted on a map exactly where the locality lies, and maps constructed in this way are eminently suitable for regional work (figs. 22, 23). Some authors use one map for each genus or species of tree and vary the size of the circles with the frequency of the pollen in the local spectrum (fig. 24). The circle methods show the essential features at a glance, but inevitably they are less accurate, and they cannot entirely replace tables or large-scale diagrams.

For the purpose of understanding the chronological import of pollen-analysis there is no need to go into greater detail. Those who are more particularly interested in the matter may be referred to H. Godwin's comprehensive summaries of the method and its potentialities (1934, 1941). Further important remarks on the principles and system of pollen-analytical datings are included in a great many papers of which I may specially mention L. von Post's paper on the age of the Svea River (1928). (Also Erdtman, p. 399.)

Climatic phases of the Postglacial. As a result of intensive research it has become clear that the climate has undergone marked fluctuations since the Last Glaciation. They were first recognized in the latter half of the nineteenth century by Blytt and Sernander who worked on the macroscopic remains of plants in southern Scandinavia, and they have since been largely confirmed by pollen-analysis.

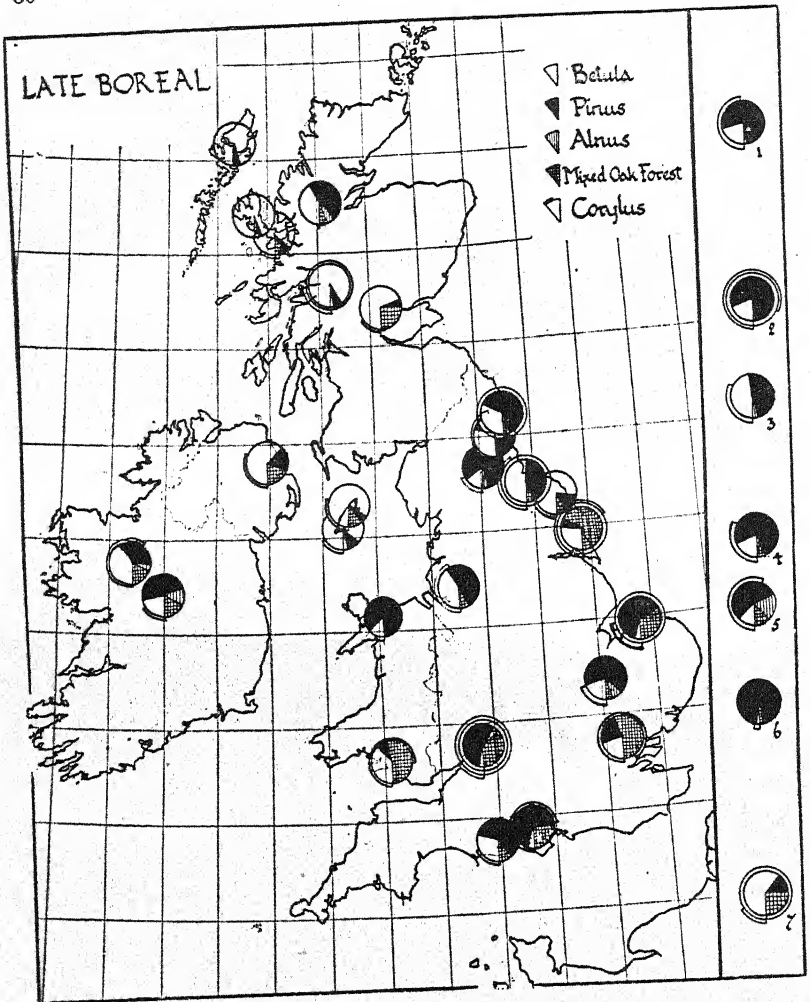
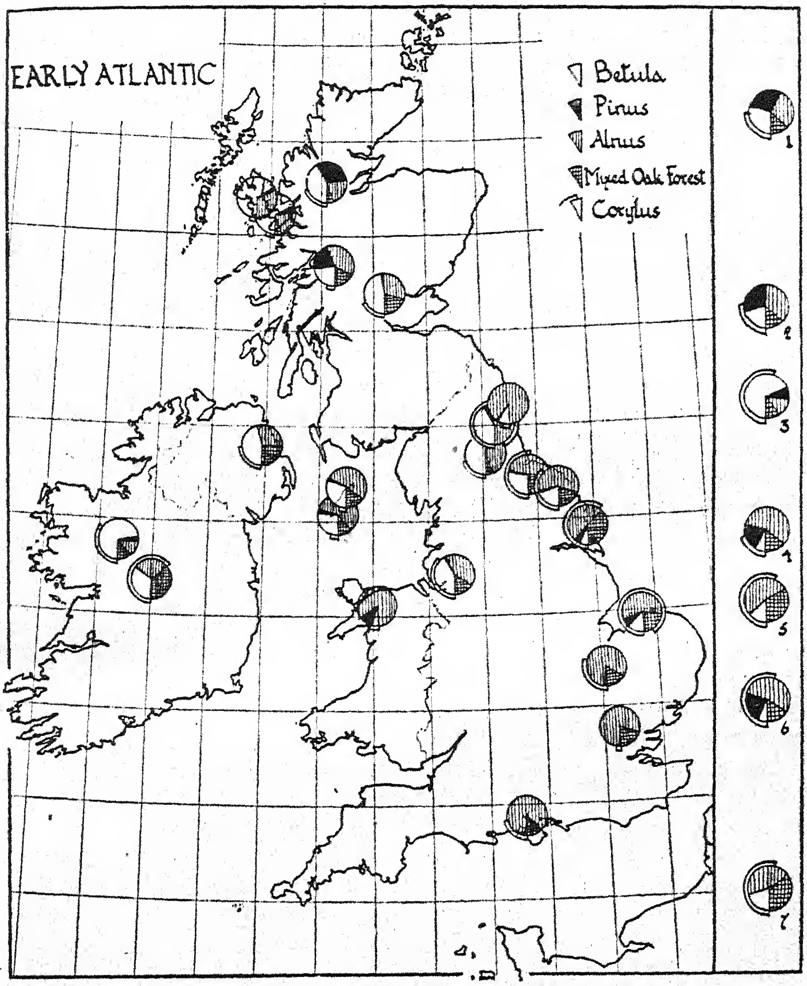


FIG. 22 and 23.—The percentage pollen composition of samples of the late diagrams of the sectorial type, 360 degrees being equal to 100 per cent. The Birch. Hatched: Elder. Crossed: Mixed Oak Forest.

The columns on the right of each figure are analyses of comparable age from is shown at its proper geographical latitude. They are (1) Göteborg, Sweden, Germany, (5) Valthermond, Holland, (6) Soesterveen, Holland, (7) south Belgium.

Reproduced from Godwin (1934,

Subarctic phases. Blytt and Sernander's original subdivisions comprise (1) a *Subarctic* phase following immediately after the retreat of the ice from the region under investigation. The term 'subarctic' is not satisfactory since the climate must have differed from the present arctic climate owing to the much lower geographical



Boreal (22) and early Atlantic (23) in the British Isles. Represented by circular
hazel is exempted and shown by subsidiary circles. Black : Pine. White :

lowland stations on the North Sea border of the Continent and the Baltic. Each
(2) Schona, south Sweden, (3) Zeeland, Denmark, (4) Dannenberg, north-west

figs. 18, 19), with permission.

latitude. The term 'subglacial' has been suggested by Hyyppä. It would be preferable were it not pre-occupied by its use in connexion with meltwater channels between the ice and the bottom moraine of glaciers.

The earlier part of the Subarctic phase is often called the *Dryas*

time, after a characteristic plant found in tundra-like environments. Treeless biotopes with tundra and grasslands prevailed though dwarf willows and birches, and perhaps a few pines, were present. In the later part of the Subarctic phase (often called the *Preboreal*) Scotch pine (*Pinus silvestris*) and birch (*Betula pubescens* and *verrucosa*) began to spread and to form the first woodlands of the region, thus initiating the following, Boreal, phase.

Alleröd oscillation. In many localties, the *Dryas* time is subdivided by a very remarkable oscillation, called the *Alleröd oscillation*. This was a time with climatic conditions more genial than before *and after*, when trees were able to grow in places from which they disappeared once more during the later *Dryas* time. In other words, it appears to have been a phase with a generally higher temperature, or with a continental climate with hotter summers and possibly colder winters. In the varve chronology, the Alleröd oscillation is placed at about 9000 to 10000 B.C. by Milthers, the ice having been on Danish soil as late as a little before 11000 B.C. In view of the reductions recently applied to the time-scale by de Geer, this figure for the Alleröd oscillation may have to be reduced. This interesting climatic fluctuation will be further discussed on p. 105.

Blytt and Sernander's subdivisions. The remainder of the Postglacial was divided by Blytt and Sernander into four parts, namely the *Boreal* phase, which was of a continental character, comparatively warm and dry; the *Atlantic* phase, which was oceanic in character, humid and mild; the *Subboreal* phase, supposed to have been drier and more continental; and finally the *Subatlantic* phase, which is marked by a return to cooler and more oceanic conditions. The continental character of the Subboreal has since been doubted and some recent authors consider it as merely a phase transitional between Atlantic and Subatlantic (see pp. 64, 106). According to von Post (1924) the evolution of the forests of south Sweden during these four phases may be summarized as follows.

(2) *Boreal.* At the beginning of this period there immigrated the first forest-forming trees requiring a comparatively warm climate. The dominating types of forest, however, were still made up of pine and birch, with alder and mixed oak forests (forests with elm and lime in addition to oak) as generally subordinate associates. In parts, hazel woods had a great extension. Later during the Boreal, mixed oak forests and forests of the river-floodplain type ('Auwälder') spread and replaced the hazel woods.

(3) *Atlantic.* The mixed oak forests culminate, and the hazel now mainly occurs as undergrowth. No regional differentiation is observed in south Sweden except that determined by latitude and character of the soil.

(4) *Subboreal.* The mixed oak forests, alder and hazel now begin to retreat. The reduction of the mixed oak forest is less striking

in south-west Götaland where *Quercus sessiliflora* now begins to increase. Pine also increases. Beech (*Fagus silvatica*), hornbeam (*Carpinus betula*) and spruce (*Picea excelsa*) are added, but as yet are rather subordinate as forest-forming elements.

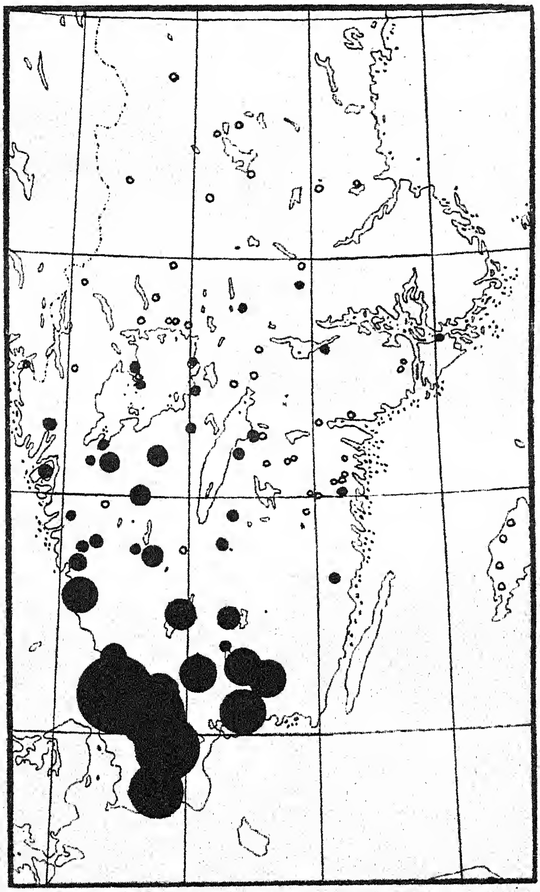


FIG. 24.—Distribution of beech and hornbeam during the middle Subatlantic in Scania. Frequency shown by the size of the black circles, the largest being 80 per cent., the smallest 1–3 per cent. Small white circles indicate localities from which the pollen in question is absent. At this period the two trees occupied several localities north of their present area of continuous distribution.—After von Post (1924), slightly simplified.

(5) *Subatlantic.* The retreat of the mixed oak forest continues. During the middle of this period the beech culminates in the south-west of the region, replacing the hitherto dominating *Quercus sessiliflora*. The spruce continues to extend its area.

Regional applicability of subdivisions. More or less similar sub-

divisions can be distinguished not only in south Sweden generally but for instance in Finland, north and south Germany, and the British Isles also. Even in the area of the North Sea the Boreal is well known from the Dogger Bank (see Godwin, 1934, p. 341), from which a fair amount of peat has been dredged and studied.

The Grenzhorizont and the Subboreal. The development from Boreal to Atlantic and then to Subatlantic is evident in most parts of temperate Europe. The same cannot be said, however, of the Subboreal, and attempts have been made to explain away the evidence brought forward in favour of it. Such evidence consists for instance in horizons of decomposed peat in bog-sections. As these beds, called *Grenzhorizont,* often are connected with *Calluna*-peat, they have been accepted as proving a temporary drying-up of the peat-bogs. Furthermore, the pine, a tree with continental tendencies, spread at about the same time and its stools are found in the peat. The Grenzhorizont is now explained in various ways as a stage in the normal development of the bog, and the local increase of pine is no longer accepted by many workers as evidence of drier conditions. The problem of the Subboreal is not settled yet, though the majority of workers are inclined to abolish it at least as a phase with a distinctly continental climate. Some authors retain the term merely as a chronological subdivision. Gross (1931) has surveyed the arguments against the reality of the Subboreal. A threefold division as suggested by von Post certainly has many advantages over the Blytt-Sernander divisions though the latter are most widely used.

Von Post's major divisions. Von Post proposes to distinguish:

(A) 'The stage of approach of the warm period, characterized by the appearance and first increase of relatively heat-loving trees of different kinds.'

(B) 'The stage of culmination of these forest elements.'

(C) 'The stage of the decrease of the characteristic trees of the warm period and the appearance or the return of the dominant forest constituents of the present day.'

New detailed subdivisions. Gotland. In recent years a new series of subdivisions has been worked out which embodies more details and at the same time enables one to avoid Blytt and Sernander's terms which many workers consider as unsatisfactory partly because of the doubtful character of the Subboreal, partly because they have often been misinterpreted, if not misused. Von Post (1925) was the first to introduce a new system of zones. These, intended for local use on the isle of Gotland, are numbered from top to bottom as follows:

I. Present time and latter part of Subatlantic; from about Viking times onwards.

II. Early and middle Subatlantic; greater part of Iron Age.

III. Subboreal; passage graves and Bronze Age.
IV. Late Atlantic; from Litorina maximum to passage graves.
V. Early Atlantic; before and near the Litorina maximum.
VI. Transition from Boreal to Atlantic.
VII. Boreal, soon after Ancylus maximum.
VIII. Boreal, during Ancylus maximum.
IX. Beginning of Postglacial warm period, just before the Ancylus maximum.
X. Subarctic phase.
XI. Arctic phase.

South Sweden. Similar zones have been used by von Post (1928) in middle Sweden, and by Nilsson (1935) in Scania (south Sweden) Nilsson's zones (fig. 25) largely coincide with von Post's for Gotland, except in the late Glacial sequence which Nilsson was able to supplement as follows: X. Younger Dryas time, XI. Alleröd oscillation, XII. Older Dryas time.

Denmark. Jessen (1935) has introduced new divisions for the late Glacial and Postglacial of Denmark. Unlike von Post's and Nilsson's Swedish zones, his zones are counted from the lowermost upwards. Jessen's divisions are as follows:

B. Postglacial period

IX. Beech zone (Subatlantic). Beech the typical tree; spruce in north Jutland. Earliest strata indicate swamping of the relatively dry surface of the Subboreal bogs. Iron Age finds always above this limit.

VIII. Later part of the Mixed Oak Forest zone (late Atlantic and Subboreal). Latest stages of the Stone Age, and Bronze Age.

VII. Early part of Mixed Oak Forest zone (larger part of Atlantic). Flourishing of oak forests. Lime prominent. The Litorina transgression, the Ertebölle (kitchenmidden) culture and presumably the earlier part of the typical Danish Neolithic belong to this phase.

VI. Hazel zone (Late Boreal). In most diagrams a high maximum of hazel occurs. Pine reduced; elm, oak, alder and lime increasing. Maglemose culture.

V. Pine zone (Early Boreal). Pine dominates. Maglemose culture.

IV. Birch-Pine zone (Preboreal, or transition from Subarctic to Boreal). Birch dominant, pine increasing. Nörre-Lyngby arrowhead presumably from beginning of this zone.

A. Late Glacial

III. Later Dryas period (Upper Dryas clay). *Dryas* flora. Maximum of pollen of pine and willow, but pine pollen probably

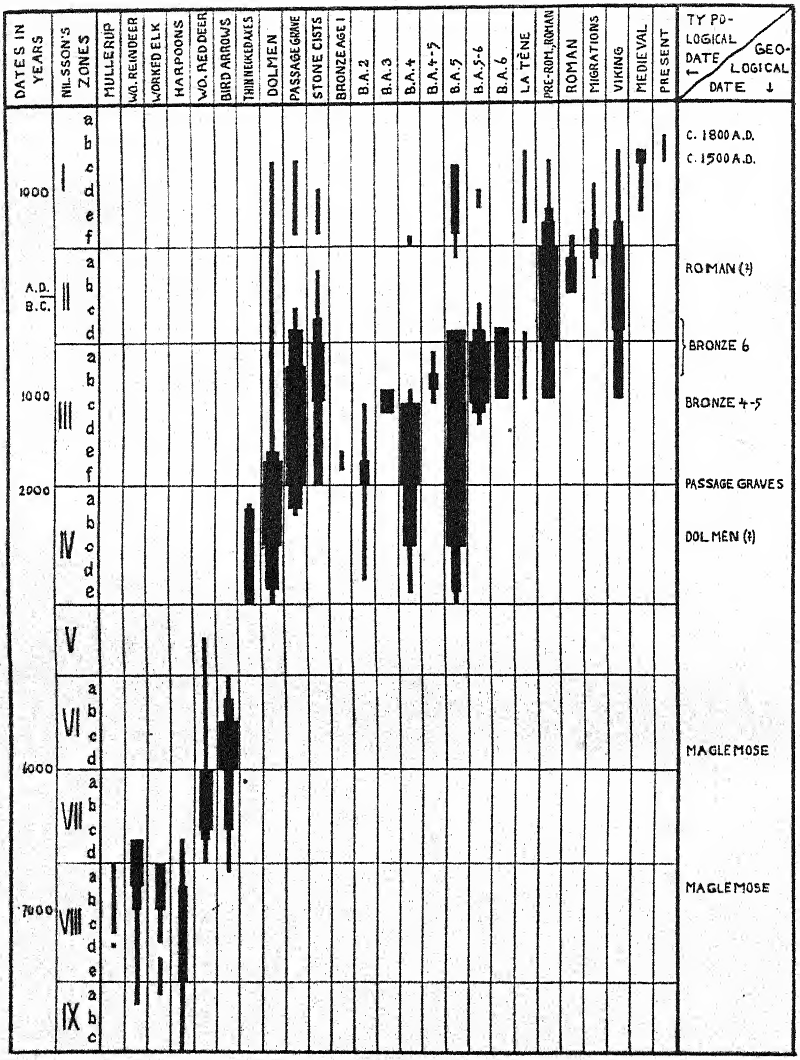


FIG. 25.—The stratigraphical distribution of archaeological finds in Scania. Objects dated typologically were fitted by Nilsson into the climatic sequence on the evidence of pollen found attached to them. Since many objects were contaminated, or had been displaced by sinking into a lower horizon or by other disturbances, the stratigraphical records sometimes cover a period far surpassing the actual period of use of the object. Taking into consideration the degree of precision obtainable in the various localities, Nilsson arrived at the geological dates given in the column on the extreme right.

The terms of the top row of the table explain themselves, except 'worked' reindeer, elk and red deer, which refer to axes made of these materials; 'harpoons' meaning bone points, and 'bird arrows' meaning bone points fitted with flint.—Based on Nilsson (1935).

derived from some distance, no macroscopic remains of pine having been found. The same applies to II and I.

II. Alleröd oscillation. Birch forest. Maximum for pollen of birch.

I. Earlier Dryas period (Lower Dryas clay). *Dryas* flora. Maximum for pollen of pine and willow.

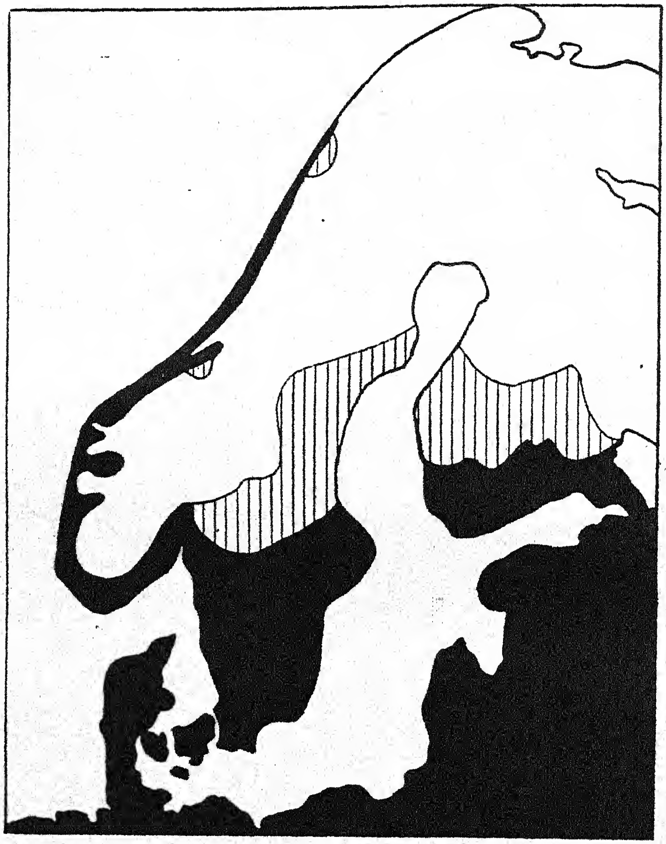
These subdivisions have proved to be particularly convenient. They have been applied (though with different numbering) to England by Godwin, as will be shown later on (p. 89). For further details concerning Sweden and Denmark, compare p. 72.

Postglacial climatic optimum. So far, one important observation has not yet been mentioned here, namely that of a distinct maximum in the spreading of warmth-loving plants in Europe. At some time during the Postglacial, certain warmth-loving plants were more widely distributed than at present, reaching higher latitudes as well as higher altitudes. A climatic explanation has been put forward for this phenomenon. A valuable account of the evidence was provided by Bertsch (1935), and a chapter in W. B. Wright's book on the Quaternary Ice Age (1937) is devoted to what is generally called the *Postglacial climatic optimum*. Bertsch mentions no fewer than twelve species which at some time during the Postglacial extended farther north than now in the Baltic region. Particularly interesting are the hazel (fig. 26), and the Slender Naias (*Naias flexilis*, fig. 27). In the Alps the retreat of the flora since the climatic optimum is equally obvious. Here, the limit of the trees was two to four hundred metres higher than at present, and the limits of the more sensitive species were correspondingly higher than now. From observations made in Scandinavia Andersson calculated that the annual mean temperature has dropped by 1·9–2·7 C. since the Postglacial optimum, and Bertsch arrives at 2·0–2·5 C. for the Alps.

The maximum of this warm phase of the Postglacial coincides in many regions with the later part of the Atlantic, but evidence for conditions warmer than now extends over a long space of time, from the Boreal to the Subboreal. The maximum seems not to have been reached everywhere at the same moment. It may be that optimum conditions occurred earlier in south Germany than in Scandinavia. Bertsch dates them for south Germany at about 8000 B.C., during the Mesolithic (Boreal), whilst in Sweden they coincide with the Neolithic (Atlantic) at about 4500 B.C., and in Denmark they are supposed to have occurred between 1000 and 2000 B.C. during the Subboreal. Some of these differences may be due to misinterpretation of evidence, but to some extent they seem to have a sound basis.

Pollen-analysis in North America. It may be mentioned in passing that pollen-analysis has been taken up in North America

also. In a recent summary of this work by Cooper (1942) it is shown that on that continent the climatic sequence was ' from glacial through boreal to a warm and probably dry middle period, followed

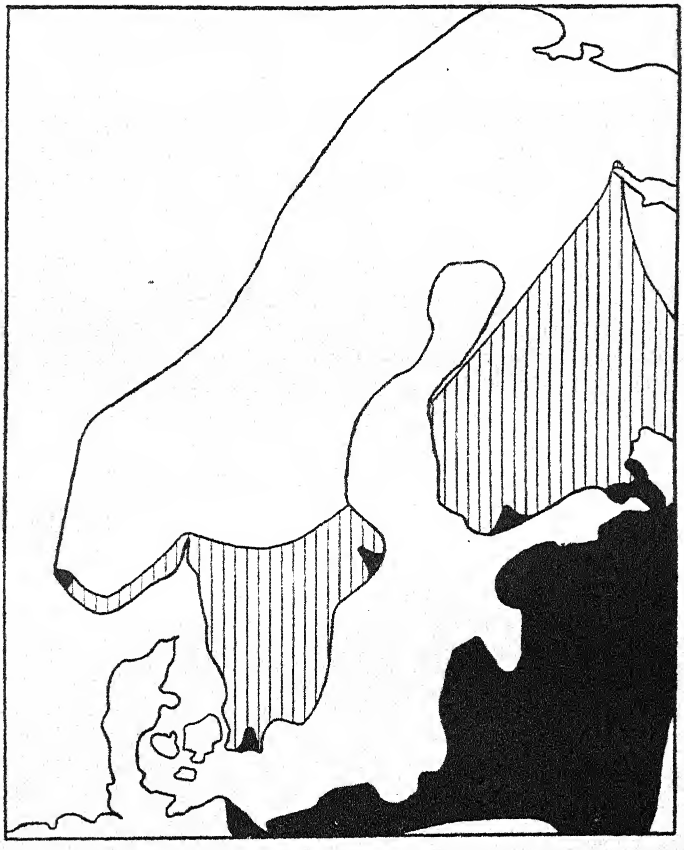


FIGS. 26 and 27.—Two examples of restriction of distribution after the Boreal present-day distribution, from which fossil finds of Postglacial age have been

FIG. 26.—Hazel (*Corylus avellana* L.). In Boreal times this shrub covered large areas in central Sweden and central Finland from which it has since disappeared. The hazel may have played an important part in the economy of the food-gathering Mesolithic tribes, and their replacement by Neolithic people may be connected with the setback the hazel suffered with the beginning of the Atlantic phase.

by a return to the cooler and probably moister conditions of the present'. Cooper advises caution, however, in calling the middle period dry, since evidence for dryness apart from warmth is very

scanty. Raup (1937) has inferred from the contemporary plant distribution that a warmer and drier period occurred in New England within the past 3,000 years.



Phase. Black: present area of distribution. Hatched: area outside the recorded.—Both figures after Bertsch (1935).

FIG. 27.—*Najas flexilis* Rostk., an annual monocotyledonous freshwater plant. It is now frequent all over North America and requires warm summers for the ripening of the seed. .During the Boreal it had a wide distribution in Scandinavia and Finland but is now restricted chiefly to the south-east side of the Baltic. In Sweden, 28 localities of Boreal age are known, compared with 5 Atlantic and Subboreal localities (Neolithic and Bronze Age), and only two from historical times.

This work has been carried on, among others, by Deevey (1943*b*, 1944) who has found the following succession, which he correlates tentatively with the phases of the European Postglacial :—

European phases	Vegetation eastern North America	Connecticut zones	Climate
Subatlantic	Oak—Chestnut—Spruce (Oak—Beech)	C-3	Cool, wet
Subboreal	Oak—Hickory	C-2	Warm, dry
Atlantic	Oak—Hemlock (Oak—Beech)	C-1	Warm, moist
Boreal	Pine	B	Warm, dry
Preboreal	Spruce—Fir	A	Cool
Arctic Subarctic Arctic	Missing in North American pollen diagrams		

Deevey is further drawing attention to the archaeological possibilities of pollen-analysis in North America, but the determinations of relative age of archaeological remains by means of pollen-analysis are, so far, of a highly tentative character, such as Hansen's suggestion that man was present during and before the dry period which is regarded as the climatic optimum, and the attempted pollen-analytical dating of a buried fish-weir near Boston (Deevey, 1944). The same author has also developed ideas of how to extend pollen-analytical dating to Mexican prehistory (1943*a*). These experiments in climatic dating in North America are most promising, though the draw-back in that continent is, for the time being, the absence of a tolerably reliable connection of vegetational phases with varve-countings.

These investigations of the North American Postglacial are important not only for that area, but for the problem of the causes of the Postglacial climatic fluctuations. The results indicated in the preceding paragraph raise the question of whether the sequences of Europe and North America agree in the presence of a Postglacial climatic optimum and perhaps even of a late dry phase of the Subboreal type; but much research will have to be done on both sides of the Atlantic before these questions can be answered and the results used in correlating the Postglacial successions of the two continents.

Correlation of sea-levels and climatic phases with varve-countings and prehistoric chronology. These introductory remarks may suffice to show how a correlation between the observed heights of former sea-levels, the climatic phases of the Postglacial and the varve-countings could be effected and how such correlation has led to the establishment of an absolute chronology for the Postglacial and its prehistoric phases.

In the countries around the Baltic peat-deposits are sometimes found resting on varved clays or otherwise connected with moraine

and glacial deposits. Although the possibility of a gap between the two cannot always be excluded varve-countings yield a maximum age for the bottom-bed of peat. The climatic phase during which the peat was formed is known thanks to pollen-analysis, and it is evident that a series of sections of this kind narrows down the possible limits for the ages of the climatic phases of the Postglacial.

On the other hand, raised beaches are sometimes connected with peat deposits which began to form soon after the beach was abandoned by the sea. The raised beaches, also, can thus be correlated with the climatic phases.

It has been mentioned above that certain prehistoric sites occur on raised beaches. In a well-investigated district as that of the Baltic, the climatic phase would therefore be known also, as would be, in many cases, the approximate age in years on the base of varve-countings. The knowledge of the climatic phase links such sites with those not situated on a beach, where pollen-analysis affords the only means of relative dating. Sites of this kind often occur in sections of peat. This means that the occupants settled on the surface of the peat at that time, and their dwelling-site was covered by a further growth of peat later on. This applies, for instance, to many Bronze Age sites (compare Federsee, Swabia, p. 86, fig. 31). Alternatively the settlement may have been on higher ground in the neighbourhood and the detrital layers only extend into the peat-bog (Magdalenian of Meiendorf for instance, p. 74, and Bronze Age of Peacock's Farm, Cambridgeshire; Clark, Godwin and Clifford, 1935). In both cases the relation of the culture to the climatic phase can be established. In this manner numerous Mesolithic, Neolithic, Bronze Age and Iron Age sites have been dated in relation to the climatic phases of the Postglacial, and since the age in years of the latter is known for reasons explained above, approximate dates can be assigned to most of the cultural phases of the Postglacial.

In the peripheral zone outside the Baltic, however, where the isostatic rise of the land after the Last Glaciation is replaced by a compensating sinking movement, or no movement at all, and where the eustatic rise of the general sea-level owing to the return of meltwater from the ice-caps resulted in a transgression of the sea, most of the early Postglacial deposits are now covered by the sea. A typical locality of this kind is the Dogger Bank which, on the evidence of its peat deposits, was dry land during the Boreal. Dredged implements of Maglemose age confirm this. Since peat of Atlantic type is restricted to a zone much nearer to the present coasts of the North Sea, the transgression must have taken place chiefly during the late Boreal and proceeded rapidly. Submerged Neolithic and even Bronze Age sites, and the many submerged forests observed along the British coasts, however, show that the trans-

gression of the sea continued into the Subboreal (fig. 34), and the final severance of Great Britain from the Continent appears to fall at the Atlantic time.

The introduction into the methods of late Glacial and Postglacial chronology given in the present and the preceding chapter will enable the reader to appreciate the evidence from selected sites and areas, which forms the subject-matter of the following chapter. After this regional review, however, it will be necessary to return to some of the striking features of this period, like the Alleröd Oscillation, the Subboreal, &c., in the concluding summary (p. 102).

CHAPTER IV

IMPORTANT SITES OF THE END OF THE OLD STONE AGE, THE MIDDLE AND NEW STONE AGES AND THE METAL AGES, AND THE PREHISTORIC CHRONOLOGY OF THE POSTGLACIAL

The number of late Glacial and Postglacial localities of temperate Europe, which are of interest from the chronological point of view, is very great. The selection presented in this chapter cannot claim to be a fair cross-section of the work done in the various countries involved; it has been made for the purpose of developing a picture of the climatic phases and their correlated prehistoric industries, preference being given to evidence obtained in recent years. Those interested in a more comprehensive review of the late Glacial and Postglacial are advised to consult the publications by Clark (1936*a*), Firbas (1939), Godwin (1940*b*, 1941), Gross (1931, 1937), and the relevant chapters in Wright (1937). On the other hand, readers who are not interested in regional details will best pass on directly to Part G of this chapter, p. 102. The correlation table, fig. 38, p. 108, might help in understanding the somewhat complicated relations between climatic and prehistoric phases. The terminology of the floral phases is summarized in fig. 28.

Since the countries around the Baltic Sea are by far the best explored as far as the late Glacial and Postglacial formations are concerned, they are regarded as the typical region. Much of Scandinavia and Finland was covered by ice until long after the maximum of the Last Glaciation, so that the earliest deposits and prehistoric finds may be expected in the south-western part of the area. Here, they have indeed come to light in the course of the last few years.

A. HOLSTEIN AND DENMARK

Meiendorf near Hamburg (*Magdalenian*). The important site of Meiendorf, in the province of Holstein, a short distance east of

Hamburg, was discovered in 1933. A detailed account has been published by Rust (1937), describing the industry and comprising contributions by Schütrumpf on the botanical finds and pollen-analytical results, on the geology by Gripp, and on the bones by W. Krause.

Major Phases	Typical Trees	Sweden	Denmark	England	Ireland
Subatlantic	Mixed Oak Forest	I, II	IX	VIII	VII
[Grenzhorizont]					
Subboreal		III	VIII	VII-VIII	VI
Atlantic		IV, V	VII	VII	upper Vb
Boreal	Hazel & Pine	VI, VII, VIII	VI, V	VI, V	lower Vb, Va
Preboreal	Birch & Pine	IX	IV	IV	IV
Upper Dryas	Tundra	X	III	III	III
Allerød	Birch & Pine	XI	II	II	II
Lower Dryas	Tundra	XII	I	I	I

FIG. 28.—The approximate correlation of the pollen-analytical phases established in southern Sweden, Denmark, England, and Ireland, with the major divisions of the late Quaternary as based on Blytt and Sernander.

Underneath a peat section of several metres thickness a reindeer hunters' settlement was uncovered, resting on a glacial varved clay (figure in Clark, 1938, p. 161). Gripp holds the view that hardly 200 years elapsed between the end of the glacial lake phase and the arrival of the reindeer hunters. The cultural horizon contains

innumerable remains of reindeer, many of them worked, and a large number of bone and flint implements. The flint implements are clearly of the Upper Palaeolithic type ('Magdalenian'), and Rust compares them with the finds from the Petersfels in south Germany (see p. 161), from Mezine (Ukraine), and the Creswellian of Derbyshire (see p. 196). The bone artefacts (harpoon, bâton de commandement, strap-cutters, &c.) also are Magdalenian in workmanship. Whilst Gripp's geological investigation shows that the occupation took place soon after the retreat of the ice from the locality, Schütrumpf's pollen-analytical and macrobotanical results demonstrate that it falls within the earliest Subarctic, tree-less phase of the Postglacial succession, i.e., the early part of the *Dryas* time. The varves underlying the deposit have not been counted yet, but since the place is just within the extreme morainic belts of the last great phase of the Last Glaciation (Pomeranian), the authors, relying on de Geer's erroneous date of 18000 B.C. (Gross, 1931, puts 19000 B.C.) suggested that the hunters' camp at Meiendorf was occupied roughly about 17000 B.C. As explained on p. 29, de Geer's figure has to be reduced, and the age of the Pomeranian is at present very uncertain. One can safely say, however, that the minimum date for the Meiendorf site is about 13000 B.C., and its actual age probably more.

The Meiendorf culture, called Hamburgian, represents the latest known true Palaeolithic. Immediately after the Meiendorf phase, the transition to the Mesolithic occurred in central and north Europe.

In view of the scarcity of late Glacial or earliest Postglacial sites the pollen-analytical succession at Meiendorf, as found by Schütrumpf, is of outstanding interest. He distinguishes the following phases:

(1) Tundra-phase without forests, but with dwarf shrubs of subarctic type. Pollen of grass and herbaceous plants is up to seven times as frequent as that of 'tree' pollen. The latter mainly consists of birch and willow (subarctic dwarf species confirmed by macroscopic finds), pine, and *Hippophae* (Sea Buckthorn). Leaves of *Dryas octopetala* were found also. This is the phase of the Hamburg-culture. It is followed by—

(2) The Birch-phase, during which the two tree-birches *Betula pubescens* and *B. verrucosa* immigrate (confirmed by macroscopical finds). Birch increases, and pine (*Pinus silvestris*) becomes more frequent in the latter half of this first forest phase, thus leading to—

(3) The Birch-pine-phase during which pine and birch compete for dominance. Their curves cross one another several times. During this phase the history of the locality as a lake is interrupted and the earlier series of lacustrine calcareous nekron-mud is replaced by a Caricetum-peat. Schütrumpf (1935) correlates this phase with the Alleröd oscillation. After this oscillation, however, the area

once more is transformed into a lake and more nekron-mud is deposited. Towards the end of this phase the pine finally defeats the birch, and—

(4) The Pine-phase begins. The lake now is nearly filled up, and *Phragmites*-peat is formed. We are in the Boreal phase of the Blytt-Sernander scheme. While pine dominates, the birch, which is frequent at first, is gradually replaced by more warmth-loving trees like hazel, oak, elm, and lime. This phase also is linked up with a prehistoric industry which Rust is inclined to consider as Tardenoisian and which in all probability is related to the Mesolithic Ahrendsburg-culture described below. In fact, nearly everywhere the Mesolithic is connected with the Boreal phase.

(5) The Mixed Oak Phase (Atlantic) is the last represented in the Meiendorf section. Its brushwood-peat in which alder is frequent produced an artefact, a possibly Neolithic core. Younger peat beds are absent.

Ahrendsburg near Hamburg (*Magdalenian and Mesolithic*). Only 600 metres north of the Meiendorf site another locality of equal importance was excavated in 1934–5. Rust, Gripp, and Schütrumpf (1935) published preliminary reports, and Rust (1936) a more elaborate description, which show that the situation of this ‘ Ahrendsburg ’ site (also called Stellmoor excavation) is similar to that of Meiendorf, namely on the slope of an elevation protruding into a subglacial valley. Two very distinct habitation levels, however, were found at Stellmoor, at depths of 5 and 6·5 metres respectively. The lower proved to belong to the Hamburgian (Meiendorf) culture, whilst the upper yielded an abundance of reindeer material worked in a manner completely different from the Hamburgian. It included a few axes of the Lyngby type (p. 76). The flint implements leave no doubt that this upper cultural level in the peat is identical with the Ahrendsburg Mesolithic found on the surface in the neighbourhood.

The pollen-analytical investigation of the peat section was carried out by R. Schütrumpf (1935). He found close agreement with the Meiendorf section. The Hamburgian level lies at the beginning of the birch-pine phase, which continues through lacustrine beds until, in a horizon of Caricetum-peat indicating drier conditions, the pine dominates temporarily over the birch. The same horizon was observed in Meiendorf and, as mentioned, Schütrumpf is inclined to regard it as the equivalent of the Alleröd oscillation. Above this horizon lacustrine conditions return and a second birch-pine phase begins. This is the time of the Mesolithic Ahrendsburg culture. The final dominance of pine, however, marking the beginning of the Boreal, did not set in until after the habitation site was covered with a further two feet of nekron-mud.

Thus Ahrendsburg proves that the Lyngby-axes belong chronologically to a cool phase of the pre-Boreal, intercalated between the

Alleröd oscillation evidenced by a pine-phase, and the Boreal proper. It is the earliest Mesolithic site that has been dated pollen-analytically, and therefore of outstanding importance.

Denmark. Meiendorf and Ahrendsburg lie at the base of the Jutland peninsula where Danish workers, especially Jessen (1920, 1935), have established a succession which in all essentials agrees with that of Sweden. Several points in this succession are of particular interest. The Alleröd oscillation once more figures in it, dividing in two the *Dryas* time.

Nörre-Lyngby (*Mesolithic*). The earliest prehistoric finds in Denmark are the well-known Nörre-Lyngby axes (Clark, 1936*a*) which were made of reindeer antler. The typical site, Lyngby, is situated at the extreme north end of Jutland. Here, a specimen was found lying on the foreshore. A tanged flint flake was extracted from a section of early Postglacial freshwater deposits in the neighbourhood (Jessen's zones III–IV), and it is likely that the axe was derived from the same deposit. The beds contained a fauna composed of tundra and forest forms and associated with a flora comprising tundra species such as *Salix polaris* and *Betula nana*. A pollen-grain of *Pinus* however was present, so that the deposit probably dates from the end of the Dryas time. Evidence for equally early dates of the Lyngby-axes has come forward in Sweden (see p. 80).

Maglemose (*Mesolithic*). Another important Danish site is Maglemose, a peat-bog near Mullerup. The Mesolithic culture named after it was one of a hunting and fishing people and had a wide distribution in the plains of north and west Europe. It was fully discussed by Clark in his book on the Mesolithic (1936*a*, see his fig. 47) so that a few remarks on the dating of the Maglemose industry will suffice here. At Maglemose itself and at the similar site of Svaerdborg bog, Jessen (1920) found on pollen-analytical evidence that the Maglemose Mesolithic belongs to the Boreal phase (= Ancylus Lake), when pine was still dominating over the mixed-oak association. Furthermore, in raised beach sections, Maglemose implements have been found to occur underneath peaty deposits of Litorina age. Submarine finds of Maglemose implements show that the level of the North Sea in those days was much lower than at present.

Ertebölle (*kitchen midden*). The third important Danish industry is that of the kitchen midden (shell-mounds). It is often termed the 'Ertebölle' culture. Many investigators correlate it with the Campignian of France and include it in the Neolithic. In Scandinavia, however, it usually is excluded from the Neolithic although pottery has been found in several sites. The shell-mounds, which are frequent in Denmark, are associated with high beach-lines of the Litorina Sea, and the same applies to Finland and Sweden.

This, as well as pollen-analytical evidence dates them as belonging to the Atlantic phase.

According to Clark (1936*a*) the Ertebölle-culture is a descendant of the Maglemose-culture (which, by the way, seems to have survived into the Atlantic in some Norwegian localities). The connexion of numerous shell-mounds with the highest beach of the Litorina Sea dates the typical Ertebölle unmistakably as of Litorina Age; but there are other sites at somewhat lower levels, and Clark supposes that a few may be beneath the present sea-level. This would indicate that the Ertebölle-culture began to develop before the Litorina transgression reached its maximum, at any rate in Denmark.

Bloksbjerg near Copenhagen. The interesting station of the Bloksbjerg near Klampenborg, not far from Copenhagen, has to be mentioned in this context. It was discovered and described by Westerby (1927). The succession (fig. 29) consists of brackish beds with shells (D and E) which prove that the hill formed an island

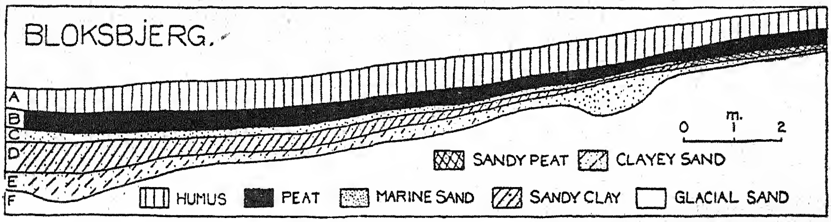


FIG. 29.—Section of the site of Bloksbjerg, a few miles north of Copenhagen, according to Westerby (1927). Reproduced from Clark (1936, fig. 49), with permission.

in a fjord while the Litorina Sea was rising to its highest level. C was formed when the sea-level once more began to recede, and was followed by the formation of the peat B. Pollen-analyses were carried out by Jessen. He found that E dates from the time when the mixed oak forest was replacing the pine (i.e. the end of the Boreal), and that D corresponded to the dominance of the mixed oak forest (i.e. the Atlantic). Thus the Bloksbjerg section suggests that the maximum of the Litorina transgression fell at the beginning of the Atlantic.[1] Archaeological objects were abundant in E, D, and C, and also in B but only in places where C was missing. In C, the typical Ertebölle culture was found, whilst the material from D and E cannot definitely be co-ordinated with others. Nevertheless it is clear that they comprise 'legacies from the Maglemose' (Clark 1936*a*). At the same time the industry of these beds, which precede, and are contemporary with, the Litorina maximum, very

[1] See, however, Troels-Smith (1937), and Iversen (1937), who recognize three Litorina transgressions in Jutland, the last of which (late Atlantic) was the highest. See also Childe (1943).

gradually merges into the typical Ertebölle industry of layer C, which was formed during the beginning of the recession.

Absolute dates for later Neolithic and Bronze Age in Denmark and elsewhere. A few words may here be said about the dating of the Metal Ages, to which southern Scandinavia has contributed so much. The methods being chiefly historical, we shall not go into details.

In the later Neolithic and in the Bronze Age, typological dating prevails over the geological methods, and the appearance of imported specimens or others which are clearly imitations of oriental prototypes has enabled archaeologists to link up the relative chronology of central and north Europe with the historical chronology of the Near East. Yet, a good many localities have been studied pollen-analytically, and it is well known for instance that the Bronze Age coincides with the Subboreal, but in such cases the absolute age is assigned to the climatic phase on the evidence of archaeology, not *vice versa*. One has, therefore, to bear in mind that many dates given in the tables for the later Neolithic, the Bronze Age and the Iron Age, were not obtained by geological methods.

As examples for the historical method, I refer to Åberg's Bronze and Iron Age chronology (1932), and to V. Gordon Childe's remarks concerning the chronology of the period IV of the Danubian Civilization (Childe, 1939, p. 119), which may be quoted:

> Exact copies of Oriental types appearing simultaneously in period IV offer an opportunity for dating the period in terms of solar years, and most chronologies of prehistoric Europe have taken them as the starting-point. But of course the age in Asia of models copied in Europe gives only a *terminus post quem* for the copies. . . . All the types mentioned . . . [previously] were current in Egypt or Mesopotamia by 2800 B.C., when Bronze was already known in the Orient. . . . Hence a long chronology placing the beginning of the Bronze Age about 2800 B.C. is defensible.
>
> On the other hand all the Oriental types relied on for dating that period enjoyed a long life. . . . The rise of the Central European bronze industry might well be connected with the extension of the amber trade to the Aegean attested first in the Shaft Graves of Mycenae about 1600 B.C. The halberd and round-heeled dagger from the same tombs strengthens this supposition; the imported fayence beads from Aunjetitz and Perjámos graves go some way to confirm it. The segmented beads from Moravia and Hungary are said to be identical with some from an Egyptian tomb dated about 1400 B.C. Violin-bow safety-pins, such as appear in Greece in the thirteenth century, have been reported from Aunjetitz tombs in Bohemia and Lower Austria. These safety-pins would at least show that the Aunjetitz culture outlasted period IV as usually defined. On the whole a short chronology would appear the more probable. Period IV should begin not earlier than 1700 B.C. . . .

This quotation illustrates well the method of cross-dating by

means of objects for which a maximum age can be established on historical evidence in the Orient. The book from which it is taken contains numerous references to the absolute chronology elaborated on this basis, and also summary tables (p. 322), so that there is no need here to go into further details.

B. SWEDEN AND NORWAY

Epipalaeolithic of Råö, Sweden. In Sweden, important finds have recently been made at Råö and Varberg in North Holland, which extend local prehistory back to almost glacial times (Niklasson, 1932). Shetelig and Falk (1937) report on them as follows:

In both places worked flints were found embedded in a stratum of marine clay which was covered by later strata; they lay about 4 metres below the present surface of the ground, which is here about 7 metres above the sea-level. The clay had been deposited at a depth of about 15 to 20 metres in the sea, and it contains shellfish which live in Arctic conditions (*Macoma calcarea* and *Saxicava arctica*). By means of the scale representing the rise of the land the period can be fixed within the years 10,000 to 9,000 B.C., corresponding to the Gothiglacial stage in the melting of the inland ice. The edge of the ice lay very near the west coast of Sweden at that time.

The flints were a secondary deposit in the clay of the sea bottom, and must have been washed out by the waves from the dwelling-stations on the shore close by. The pieces show an extraordinarily primitive treatment of the flint. There are practically no definitely established types of designed forms, only pieces split at random and made usable by a minimum of chipping. The flints can be distinguished according to their use as scrapers and hollow scrapers, planes, gravers, borers, handaxes, pointed chopping-tools, &c. In spite of the rudimentary technique, in their form and appearance a close relationship with the late palaeolithic flint work stands out clearly, especially with Aurignacian, and likewise with the palaeolithic types in Finmark, of which we shall say more later.

Komsa and Fosna cultures of northern Norway. The concluding remark of this quotation refers to the Komsa culture of the extreme north of Norway which, typologically, is essentially Palaeolithic (Nummedal, 1926). It is found in dwelling-sites on raised beaches of the Arctic Ocean and is regarded as late Glacial and early Postglacial by Nordhagen. In these remote regions, Palaeolithic tradition appears to have survived into the Postglacial.

An equally interesting survival is the Fosna culture found along the west coast of Norway, often in sites which are close to landing places (Nummedal, 1923, 1929, Shetelig and Falk, 1937, Clark, 1936*a*). Typologically, the Fosna flints are reminiscent of the late Palaeolithic and early Mesolithic. At Kristiansund, an island on the west coast of Norway, 63 N. lat., sites occur at varying heights, an important one being about 44 metres above the present level of

the sea (Nummedal, 1923). As the level corresponding to the Ancylus Lake period of the Baltic is 30 metres, these sites would be contemporary with the Ice Lake period of the Baltic, and therefore with the Råö–Varberg culture of Sweden (about 9000 to 10000 B.C.). At Kristiansund, a large tanged flake was found in clay deposited during the *Pholas* stage which corresponds to the early Ancylus Lake. This flake is reminiscent of that found at the Lyngby site and mentioned on p. 76. It supports the view that the Fosna culture is approximately contemporary with Nörre-Lyngby, and earlier than Maglemose.

These earliest Scandinavian cultures appear to continue the tradition of the Hamburgian, and it is conceivable that their bearers withdrew with the waning ice-sheet, gradually being pushed northwards by spreading Mesolithic tribes.

Mesolithic and later industries in Scania. Returning to Sweden we find evidence of Mesolithic in Scania. Here, Lyngby axes have been dated pollen-analytically. One of them, from the Bara lilla bog near Malmö, dates from the time when the mixed oak forest had not arrived and even hazel was rare (Clark, 1936*a*). This specimen is obviously pre-Boreal. Another specimen, however, found at Hylteberga in south Scania, is later, i.e. Boreal. In both cases the peaty matter attached to the specimen was studied, not the section itself.

From these two Swedish axes it appears that the Nörre-Lyngby culture in the Scandinavian peninsula began in pre-Boreal times and survived into the Boreal, so that this culture can roughly be dated from 9000 to 7000 B.C.

The extensive pollen-analytical work done in Scania by himself and others has been described by Nilsson (1935) in a comprehensive and important paper. Several of his sections fulfil the condition of linkage between the pollen-bearing series and the varved clays and some of them should, in due course, afford a chance of dating by means of direct varve counts. So far only the connexion of the bottom strata of the sections with certain moraines which, in turn, belong to de Geer's Gotiglacial, gives a rough idea of their age. Even this is important enough, since it proves that the Alleröd oscillation forms part of the Gotiglacial recession.

A good example is the bog called Baremosse, in western Scania, where the Swedish pollen-stratum XII (= I of Denmark and Britain) is amply represented in the form of varved clay. A Maglemose settlement was found higher up in the profile (von Post, 1928); it corresponds to the pollen-zone VIII (Ancylus Lake, Boreal). At other sites, Nilsson has studied the connexion of pollen-bearing deposits with raised beaches. The resulting chronology is shown here in figs. 25 and 30.

Limhamn-Trindyx (early Neolithic) of Gotland. For the dating

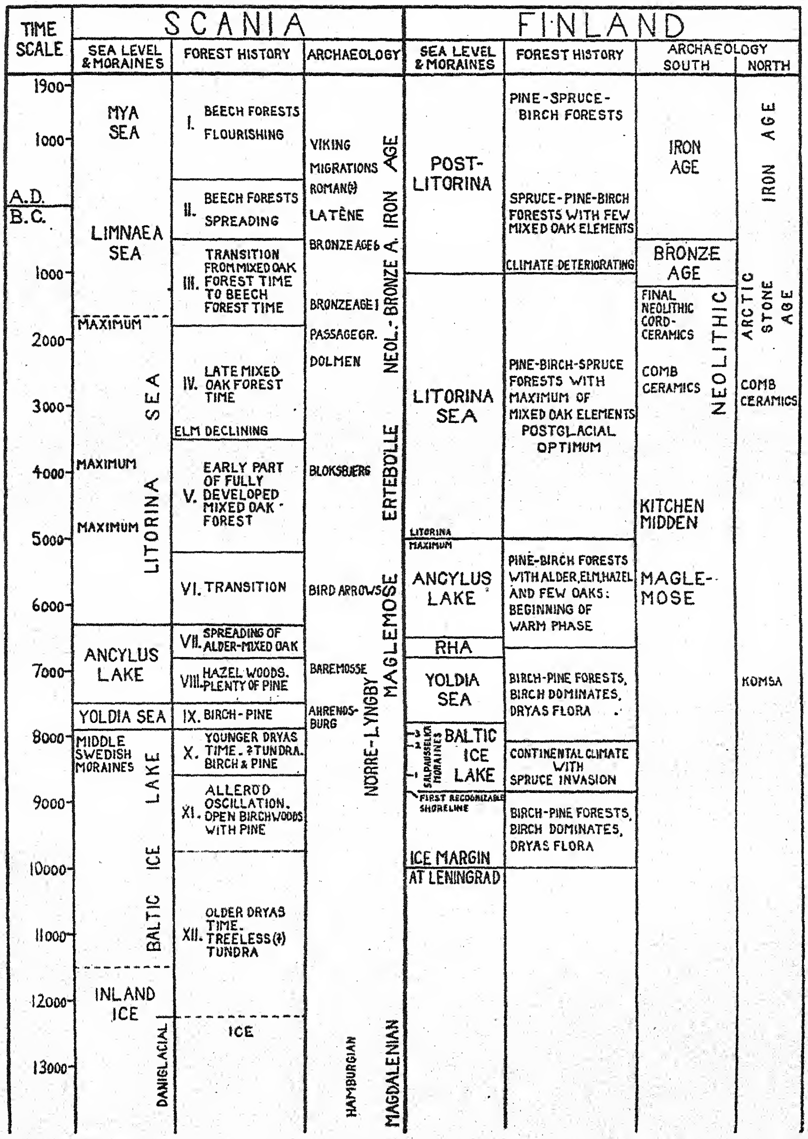


FIG. 30.—Correlation table for the late Quaternary of Scania (south Sweden) and Finland. For Scania, based on Nilsson (1935) with various additions; for Finland, on Sauramo (1939), Hyyppä, Lidén, Fromm, Europaeus, Tanner.

of the various Neolithic cultures the isle of Gotland may be taken as an example. Its geology was studied by Munthe, Hede, and von Post (1925). Many of the dwelling-sites have a very definite relation to the beaches of the Ancylus Lake or the Litorina Sea.

The only site known in Gotland which is likely to be Maglemose is that of Svalings in the parish of Gothem. It is enclosed between two beds of freshwater shore-deposits, of which the upper contains *Ancylus fluviatilis*. This, in turn, is covered by a deposit of the Litorina Sea. The section thus supports the view that Svalings is of Ancylus, or Boreal, Age.

The beginning of the kitchen midden age, which we refer to the early Neolithic, is well marked by a large number of sites associated with the coast-line of the Litorina Sea. They are characterized by stone axes of the *Limhamn* type (the 'Limhamn trindyx').

Passage graves in Gotland. The sites of the period of the passage graves, among them the rich locality Gullrum, are situated *below* the maximum level of the Litorina Sea, at a height of about 60 to 70 per cent. of the height of the maximum level. This enabled the investigators to determine the age of the passage graves at about 2400 B.C., a result that compares well with 2200 B.C. as found by Danish workers.

These few instances show how sea-levels and pollen-analysis have been used in the dating of prehistoric cultures in Scandinavia. In the Bronze and Iron Ages, pollen-analysis is almost the only applicable geological method, and it is amply supplemented by historical research. In Gotland, the Bronze Age is counted from 1800 B.C. to 800 B.C., the Iron Age from 800 B.C. to 1050 A.D., and the historic period from 1050 A.D. onwards.

C. FINLAND

Postglacial and Prehistory in Finland. In Finland the geological history of the Postglacial, especially the relations between ice-recession, varved clays, and raised beaches, have been investigated in great detail. Many of the outstanding achievements are due to M. Sauramo's untiring energy. Some of his results have been touched upon above (pp. 32, 47); it now remains to explain how the connexion of the varve-chronology with the climatic development and the sequence of prehistoric phases was established. Most of the prehistoric phases observed in Finland have been dated on the evidence of their situation in relation to the raised beaches. The most conspicuous beach-line is that of the maximum of the Litorina Sea. Its height above the present sea-level varies, the upheaval having proceeded at different rates in different areas. Near Viborg (east Finland) it is just over 20 metres above the present sea-level, at Helsinki (Helsingfors) 32 to 33 metres, and at Åbo (west Finland) about 50 metres. Thus, the height in metres of a dwelling-site is no direct indication of its age, and investigators now prefer to

give the height in percentage of the height of the Litorina maximum in the same district. Instances will be given presently.

Pollen-analysis takes second place in Finnish dating work, but it has succeeded in establishing the local climatic development in great detail. As an example for pollen-dating, the Neolithic hearth of Mutala described by Pälsi and Sauramo (1937) may be mentioned, as well as the Mesolithic site of Antrea (see below). Valuable palaeoclimatological work, particularly on the early Postglacial, has been done by E. Hyyppä (1933, 1936). He discovered that early in late Glacial times, during the period of the Baltic Ice Lake, the spruce spread in a remarkable manner, whilst later on it lost ground again. The spruce is a tree which prefers a continental climate with warm summers and cold winters. Hyyppä therefore interpreted his observations as indicating a 'late Glacial warmth-phase with warm continental summers'. The similarity of this phase with the Alleröd oscillation is striking. It was preceded and followed by Dryas phases during which, however, birch-pine forests were present. Later on, during the Ancylus Lake, pine began to dominate over birch. This time corresponds to the Boreal. With the Litorina transgression the mixed oak forest spreads but is unable to replace the pine-birch-spruce association in this northerly region. This is the time of optimum conditions of climate. The deterioration of the climate after the optimum is evidenced by a decrease of the mixed oak component in the pollen-spectra. The peat-sections investigated by Hyyppä were situated on levels which could be identified with stages of the Baltic sea. The diatom flora contained in the bottom layers proved to be a great help in identifying these stages.

In our table (fig. 30), Hyyppä's results are correlated with those obtained by Sauramo (1939) concerning the beaches and the varves. The ensuing absolute chronology for the Postglacial can be regarded as the most reliable at present available.

Chronology of Mesolithic and Neolithic in Finland. The succession of the prehistoric cultures in Finland has been studied, among others, by A. Europaeus (= A. Äyräpää; 1925, 1926, 1930). In the southern half of Finland the earliest known finds are an ice-pick made of bone, from Kyrkslätt, and the fishing-net from Antrea (south-east Finland). Both date from the Ancylus period and may be correlated with the Maglemose culture of Scandinavia. The finds made at Antrea were described by Pälsi and Lindberg (1920). The site lies below the ancient high level of Lake Ladoga on a sandy loam and is covered by nekron-mud and peat. Beside bone and stone implements the remains of a fishing-net were found, the cord of which was still partly preserved as were the floats and sinkers. Lindberg studied botanically over a hundred samples in a vertical section and was able to determine the age of the net-horizon as

Ancylus Lake. Not only the pollen but the diatoms also confirmed this result which shows that late Mesolithic man inhabited the northern part of the Baltic as well as south Sweden and Denmark. The absolute date of the Antrea finds is roughly 5500 to 6000 B.C.

The earliest Neolithic, as yet without pottery, is represented by the Suomusjärvi-culture of which numerous dwelling-sites have been detected at, or just above, the maximum Litorina beach. Typologically they correspond to the Danish kitchen midden culture (Ertebölle), though flint is replaced by slate and other rocks. Sauramo dates the Litorina maximum at 5000 B.C., and this approximate date has to be assigned to the Finnish kitchen midden phase.

The sites of the Neolithic proper can be distributed over a number of cultural phases and correlated with beach-lines; the younger an industrial phase is typologically, the lower the beach on which it is found. Like his predecessors, Neolithic man in Finland was largely dependent on fishing. This is why his dwelling-sites are found on the beaches, fortunately for us, since it makes accurate dating possible. Most of the Finnish Neolithic belongs to the combed and pitted ware group, which Europaeus suspects to be of eastern origin. It is distinct from the contemporary Scandinavian Neolithic. During the late Neolithic, however, an invasion took place by a people with corded ware ('boat-axe culture') which chiefly settled in the south-west. The invaders did not stay near the shore but settled in the areas of loamy soil. Yet a few of their sites are found on the shore so that the relation to the history of the Baltic could be established. The final Neolithic can be regarded as a continuation of the combed ware culture. It is again confined to the shore-lines. In the following table, which is abstracted from Europaeus's monograph of the Finnish Stone Age (1930), the absolute figures given are corrected in accordance with Sauramo (1939). Europaeus puts the end of the Finnish Neolithic as late as 1200 B.C.

Cultural phase	% height in relation to Litorina-maximum	Approximate date
Final Neolithic (Kiukais ware, derived from combed ware)	50–40%	1600–1200 B.C.
Corded ware or boat- (hammer-) axe culture	60–50%	2000–1600 B.C.
III: Degenerate combed ware	68–64%	till *c.* 2000 B.C.
II: Typical combed ware	75–68%	early phase *c.* 2400 B.C.
I_2: Younger early combed ware	87–76%	I_2: *c.* 2700 B.C.
I_1: Older early combed ware		I_1: *c.* 3300 B.C.

As elsewhere, the Metal Ages in Finland are dated predominantly by historical and typological methods.

D. SOUTH-WEST GERMANY AND NORTH-EAST FRANCE

South-west Germany (*Federsee; Mesolithic, Neolithic, Metal Ages*). We now leave the Baltic region and turn to the south-west

of central Europe, where Bertsch has carried out brilliant pollen-analytical work. The standard district for this region is the Federsee in Swabia, a large bog which has yielded hundreds of prehistoric stations and whose floral history has been worked out in great detail. Bertsch has recently published a valuable summary (1935) from which the accompanying diagram (fig. 31) is taken.

At the southern margin of the Federsee bog is situated the Magdalenian station called Schussenried. Remains of numerous reindeer, beside other arctic animals like polar fox and glutton were found here. The mosses belong to species which now range from middle to arctic Europe. Pollen is almost entirely absent. This deposit clearly dates from a thoroughly glacial phase.

In the inner part of the Federsee-bog, the bottom layers with *Salix polaris, Dryas octopetala, Betula nana,* &c., are regarded as contemporaneous with the Schussenried site. Whether they are so or not is difficult to decide. There certainly would be no objection to having a Magdalenian site at the height of the last glacial phase, since Meiendorf was found, but the Schussenried Magdalenian is considered typologically as middle Magdalenian. It may therefore be earlier than the Pomeranian phase, and possibly date from the second phase of the Last Glaciation or the interstadial between these two cold phases (see p. 161).

There follows on the arctic bed in the inner Federsee bog a series of lacustrine muds in which no prehistoric finds have been made. It comprises a *Pinus montana*-time, a birch-time, and a *Pinus silvestris*-time. Then, hazel begins to increase, and with it the Mesolithic appears. At this time hazel-scrublands with interspersed groups of birch and pine, oak and elm, poplar and alder covered the country. The Mesolithic site of Moosburg begins with the increase of hazel when the latter is becoming more frequent than the birch; it lasts through the hazel maximum until the time when the decreasing *Pinus*-curve cuts the increasing curve of the mixed oak forest. This, in Bertsch's scale, would date it from 9500 to 6500 B.C., but in his table (fig. 31) he extends the Mesolithic until the mixed oak forest begins to dominate over the hazel (5000 B.C.).

Of the large number of dated Neolithic sites, the spectrum of Riedschachen shows that the late Neolithic is contemporary with the latter part of the period of the mixed oak forests, when the beech immigrates. The middle Neolithic and the early Neolithic occurred during the maximum extension of the mixed oak forest.

The Bronze age is the period of the beech (fig. 32) and approximately equivalent to the Subboreal. It is important to note that the maximum of frequency of the beech, which occurs at 800 B.C. in the Federsee area, is either earlier or later elsewhere. Bertsch found that this tree immigrated into central Europe from two refuges, one

in the Balkan peninsula, and one in south-west Europe. He was able to date the migration as shown in fig. 32. Correspondingly, the beech-maximum is retarded in a northward direction. In

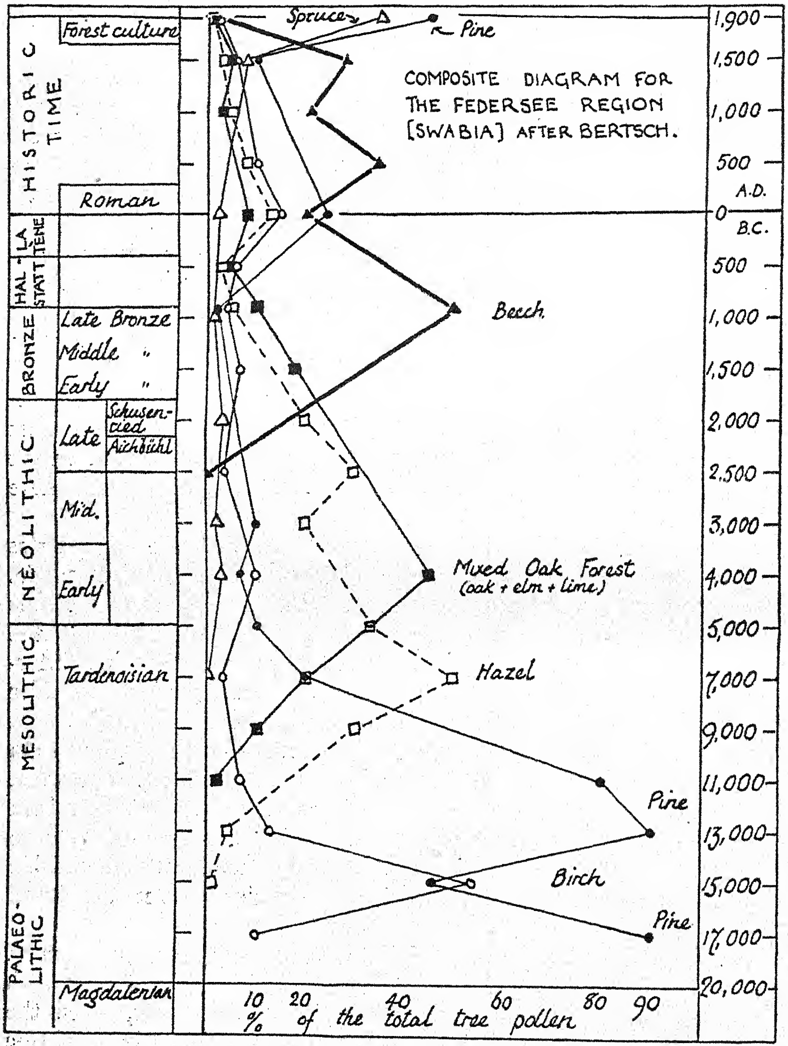


FIG. 31.—Composite diagram of the pollen composition of the peats of the Federsee Bog, in upper Swabia, south-west Germany, after Bertsch (1935), archaeology after Reinerth.—Reproduced from Godwin (1934), with permission.

Bohemia and its northern mountain ranges it coincides with the Bronze Age as it does in south-west Germany, but in Slesvig it did not occur before 500–700 A.D. This instance illustrates well the

difficulty of purely pollen-analytical cross-dating over long distances. It is obvious that a similar retardation occurred with other kinds of trees also. Fortunately, the effect of this retardation on dating is less serious in the early phases of the Postglacial when the cultural phases persisted for a longer time.

From the wealth of evidence available to him, Bertsch constructed an average pollen-diagram for his part of south-west Germany (fig. 31). His absolute dates, however, are not based on direct local evidence (varves being absent) but are interpolated between three known dates, namely the approximate climax of the last glacial phase (18000–20000 B.C.), the Postglacial maximum of solar radiation (8000–9000 B.C.), and the well-established chronology of the Neolithic and Metal Ages. His figures, therefore, are not

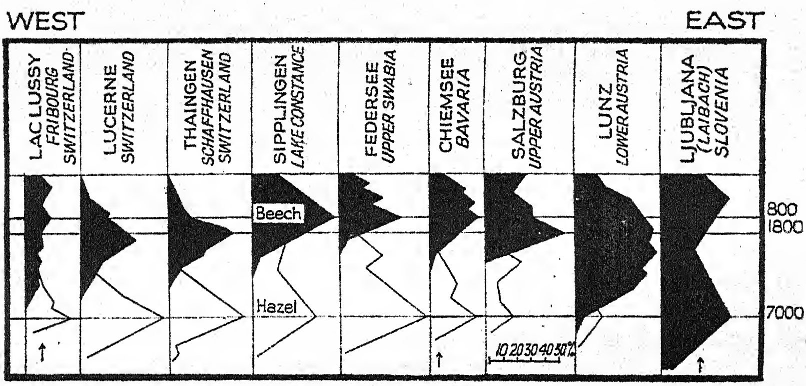


FIG. 32.—The re-immigration of the beech into south Germany from its western and eastern refuge areas after the Last Glaciation.—After Bertsch (1935).

strictly comparable with those based on the varve method. Nevertheless, comparing his results with those obtained in the Baltic area a general retardation of the flora and the early cultural phases in the north becomes apparent. Whether it is real or not, depends on the accuracy of the respective time-scales used, though it must be admitted that the result is reasonable.

North-east France. In the Vosges and the adjacent parts of north-east France, the evolution of the forests under the influence of the Postglacial climatic changes was largely the same as in south-west Germany, subject of course to modifications due to the altitude of the locality. The beech appeared earlier, however, and in the northern Vosges, the mountain pine played an important part in the Boreal. The relation of the cultural phases to the climatic periods is the same as east of the Rhine. A valuable summary has been published by Dubois (1938).

E. NORTH-WEST GERMANY

North-west Germany. The north-west German lowlands with their extensive peat-bogs form a natural link between central Europe and east England. Their climate is more oceanic than that of east and south Germany but less so than that of England. Moreover, submerged peat occurs on the German coast and has enabled workers to reconstruct the transgression of the North Sea. The same has been done, on similar lines, in eastern England. Yet it was not until a few years ago that, on the initiative of F. Overbeck, extensive pollen-analytical work was begun in north-west Germany.

According to Overbeck (1933; Overbeck and Schmitz, 1931) the general succession in north-west Germany is similar to that of other parts of temperate Europe. The following phases have been distinguished: birch-pine, pine-hazel, oak-hazel, beech-oak, beech-oak-hornbeam, and culture-spectra influenced by man. There are distinct differences between the north-west and the south-east of north-west Germany, caused by the greater continentality of the climate in the districts farther from the coast. During the Preboreal and early Boreal, much of the North Sea, including the Dogger Bank, was dry land, and the continental character of the climate of what is now north-west Germany was pronounced. The mixed oak association began to spread, but the pine dominated the whole area. During the Atlantic the pine retreated eastwards so that about the middle of this phase the pine had become rare in the north-western part. By this time, the sea had advanced practically to the present-day coast-line. During the Subatlantic the beech, which had been present throughout the second half of the Atlantic attained its maximum, especially in the east where it became more frequent than the oak.

A well-marked Grenzhorizont (see p. 64) separates the Atlantic from the Subatlantic, and it is here that this type of unconformity in peat-sections was first observed (Weber, 1910). There is no clear evidence of a drier Subboreal phase, according to Schubert (1933), and the change at the Grenzhorizont is explained as due to a change in the conditions of peat-formation, not to weathering under a drier climate.

Much of north-west Germany is now covered with heathlands (*Calluna*-heath). Overbeck found that this was not the case in the earlier phases of the Postglacial and that the forests did not begin to give way to heathlands before the Subboreal. He is inclined to attribute this change to interference by man, who destroyed the forests and introduced domesticated animals which prevented the young tree-growth from coming up. In other words, the same factor which is responsible for the deforestation in the Mediterranean region would have caused the spreading of heaths in north-west Germany and the adjoining countries.

The correlation of the levels of the North Sea affords a check on the Scandinavian system and also a parallel with the conditions observed on the coast of eastern England. The Dogger Bank is known to have been dry in the early Boreal (p. 92), and Maglemose implements were dredged from it. It appears to have become submerged rapidly during the second half of the Boreal, and the coast-line retreated equally rapidly approximately to its present position, so that marshlands began to form in the early Atlantic. This is also the time of the maximum transgression of the Litorina Sea, and since the Baltic was then connected with the North Sea, it is very likely that the transgressions in both areas were contemporaneous. We thus obtain an important fixed point in our chronology. It further shows that the beginning of the great phase of oceanic climate (the Atlantic) coincides with the maximum transgression which must have intensified the oceanic character of the climate. On the other hand, what little remains of indications of a slightly drier climate during the Subboreal coincides with indications of a temporary drop in sea-level, and it is not impossible that the two phenomena are causally connected.

As one is justified in applying to the North Sea at least the date for the Litorina Transgression obtained in the Baltic and since, from the Bronze Age onwards, historical correlation provides more comparable dates, the absolute chronology of the North Sea area can be regarded as reliable in the outlines. It places the Mesolithic at about 6000–7000 B.C., the Neolithic around 4000 B.C., the Bronze Age from 1800 B.C. onwards, and the limit towards the Iron Age at 800 B.C.

F. BRITAIN AND IRELAND

Britain. The credit of having introduced the method of pollen-analysis into the British Isles is due to G. Erdtman, a well-known Swedish palaeobotanist. In 1928, he published the results of a preliminary survey of peat deposits in Britain, in which he was able to show that the general development of the Postglacial in this country was the same as in Scandinavia. Few workers, however, took up this promising line of research, among them Raistrick (1931, 1932), until, in 1934, H. Godwin began a systematic campaign with the view to establishing the details of Postglacial forest history in Britain. His successful work is largely based on the deposits of the Fenland which adjoins the large bay known as the Wash, in eastern England (Godwin, 1938, 1940*a*).

Godwin found that the succession of tree associations in eastern England resembles that of Denmark fairly closely and established a system of zones (1940*b*) resembling that of Jessen, as follows, beginning with the latest deposit (fig. 33):—

VIII. Alder-oak-elm-birch-beech zone, representing the Sub-

atlantic with an increase of birch at the expense of the warmth-loving mixed oak forest. Climate cooler than in the preceding period. It is not until this period that the beech becomes a little more prominent in England.

VII–VIII. Transitional level, the lower portion of which corresponds to the later 'Subboreal'. In peat-bogs, the Grenzhorizont is often clearly marked, separating the lower from the upper *Sphagnum* peat. It is certain that the upper *Sphagnum* peat was formed in a climate decidedly wetter than that of the lower, but it is doubtful whether the limit itself represents a dry phase. Godwin remarks that the lower peat was formed under conditions which were drier

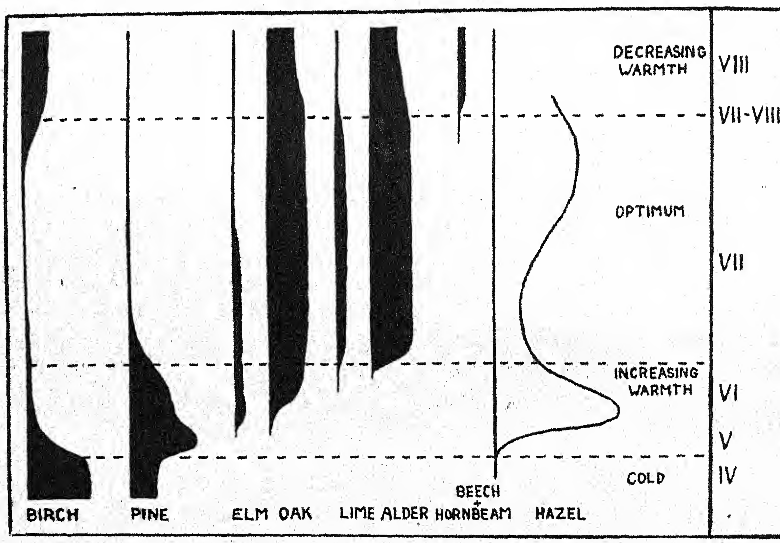


FIG. 33.—Forest development in eastern England, according to Godwin (1940).

throughout, compared with the upper, in other words that the climate of the Atlantic was drier than that of the Subatlantic. He bases his view on the observation that the Grenzhorizont is not a weathering soil which decreases in intensity downwards, but merely a dividing line between two kinds of peat, each of which is more or less homogeneous. The deterioration of the climate at the beginning of the Subatlantic must have been sudden; it marks the beginning of blanket-peat formation in many localities which, up to then, had been entirely free from peat. This extension and intensification of peat formation post-dates the Neolithic and Bronze Age, traces of which have often been found buried by Subatlantic peat.

VII. Alder-oak-elm-lime zone. Mixed oak forest, with oak and alder dominating, whilst lime is characteristic. Optimum conditions

of warmth, climate comparatively damp. Atlantic phase, and early part of Subboreal.

VI. Pine-hazel zone. The transition from VI to VII is very distinct in the diagrams. The alder increases very suddenly, whilst the pine is greatly reduced. Oak and elm begin to increase earlier, in the course of the formation of zone VI. The hazel plays a very great part in all the diagrams. The climax of hazel falls at the earlier part of zone VI; it decreases in the higher levels, as the elements of the mixed oak association are spreading. Zone VI represents most of the Boreal of Blytt and Sernander.

V. Pine zone. Pollen of warmth-loving trees are practically absent, and the pine dominates. The only other pollen present in numbers is that of the birch, and that of hazel which increases rapidly towards the end of this phase. This is the early part of the Boreal.

IV. Birch-Pine zone. The birch dominates over the pine. Only very small quantities of pollen of the warmth-loving trees are present. The willow, however, is comparatively important (as in zone V also), and the amount of non-tree pollen is very large. This indicates a more or less open country with plenty of herbaceous vegetation and birch woods interspersed with pine. This phase corresponds to the Preboreal of continental Europe.

III, II, I. These divisions have been reserved for the equivalents of the *Dryas* clays and the Alleröd oscillation by Godwin who states that a corresponding series has so far been found only at one site in England, at Hawke's Tor, on Bodmin Moor, Cornwall (Godwin, 1940 b, p. 393). In Ireland, deposits of this age are better known (see p. 100). (See also p. 399, Godwin, 1941, 1943.)

Absolute chronology. This succession resembles that of southern Scandinavia. Unfortunately no section has up to now been investigated which is connected with varved clays, so that varve dating cannot be applied directly to the British series. In view of the close agreement of the British and Danish sequences and of the fact that, from the Boreal onwards, the gradual submergence of the North Sea (Litorina transgression) has influenced the climatic character of both countries, one may tentatively apply to Britain the dates obtained in southern Scandinavia.

Archaeology. On a number of occasions, Godwin has been able to correlate prehistoric sites and single implements with zones of forest development. He has summarized his results in several tables (1938, 1940*a*, *b*, *c*).

The earliest find is a Maglemose harpoon (Mesolithic II), dredged from the North Sea between the Leman and Ower Banks. It is of late Preboreal or early Boreal Age, according to the peat that was attached to it (transition zone V–VI). Another Mesolithic harpoon, from Skipsea, Yorkshire, came from zone VI. The late Tardenoisian

of Peacock's Farm (Clark, Godwin and Clifford, 1935; Clark, 1936*a*; our pl. V, fig. B) lay underneath the peat of zone VII, and a microlithic flake from Plantation Farm (these two sites are in the Fenland) came from zone VIc. The Maglemose and Tardenoisian industries (except the final Tardenoisian) thus appear to correspond to the Boreal. More details about the Mesolithic will be found in J. G. D. Clark's books on the subject (1932, 1936*a*).

The Neolithic coincides with zone VII (Atlantic), as evidenced by several finds from Peacock's Farm (Pl. V fig. B), Meare Heath, Swaffham and Hunstanton, all in the neighbourhood of the Cambridgeshire Fenland. The early Bronze Age appears in various localities in the uppermost levels of zone VII. The middle and late Bronze Ages appear to be confined to the transitional zone VII–VIII (Godwin, in Godwin and Clark, 1940*c*). This agrees well with the Continental dates for the Bronze Age. The same transitional zone VII–VIII has yielded Hallstatt remains at Ingoldmells, whilst VIII, the Subatlantic, contains the Iron Age and Romano-British material.

This correlation of archaeological finds and history of the forests is consistent with the results obtained in other regions.

Postglacial transgression of the sea. Fenland succession. The rise of the sea from its low level early in Postglacial times up to the present high level (fig. 34) has been investigated in the Fenland by H. Godwin (1934, 1940*a*). Submerged peat from the bottom of the North Sea shows that in the Preboreal (zone IV) land existed where there are now 18 to 29 fathoms (32 to 52 metres) of water. On the other hand, peat from a depth of 19 to 20 fathoms (35 metres), between the Leman and Ower Banks, which yielded a Maglemose harpoon, dates from the transition from zone V to zone VI (early Boreal). During the Atlantic, the water level passed the minus 20·5 ft.-mark (— 6 metres) and rapidly reached, and even slightly exceeded, the present sea-level. This part of the transgression has left an apparently complete record at Wiggenhall St. Germans (Godwin and Edmunds, 1933), near King's Lynn. The beds and the corresponding sea-levels are as follows (interpretation by Godwin, 1940*a*):

	Pollen zone	Sea-level at
Peat bed A	VII*a* or *b*	— 23·5 ft.
Brakish water clay B	—	— 10·5 ft.
Peat bed C	?VII*b*	— 17 ft.
Blue clay D	VII*c* and *d*	+ 2 ft.
Peat bed E, base	—	— 5–10 ft.
Peat bed E, top	VII–VIII	— 11 ft.
Scrobicularia clay F	—	+ 2–5 ft.
Peat bed H	VIII	— 7–8 ft.

The record of peat bed A, combined with the records from the Boreal and the Preboreal, shows that the rise of the sea-level was extremely rapid in the early stages, namely about one metre per

century. There is reason to suppose that the rate was even higher during the Preboreal and Boreal, and during the early Atlantic correspondingly lower, since observations made on the coast of north Germany indicate that marshlands began to form between

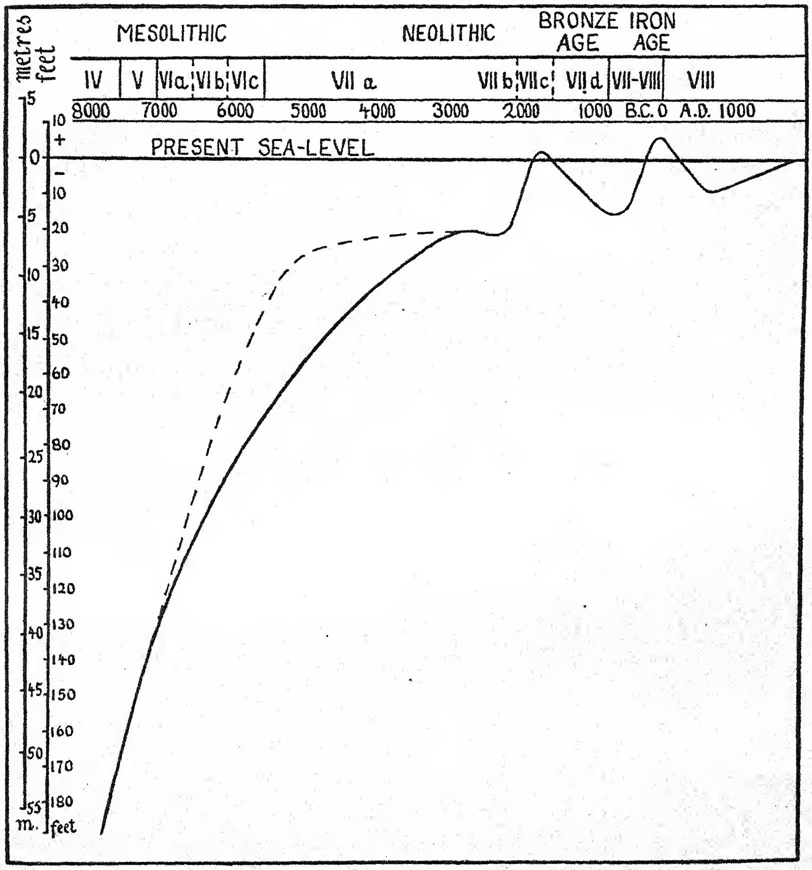


FIG. 34.—The rise of the sea-level after the Last Glaciation in southern Britain (i.e. outside the area of isostatic re-adjustment).—Based on Godwin (1940). The dotted line represents a possible alternative, and the suggested pre-Neolithic high level is not shown.

5000 and 6000 B.C., at the *beginning* of the Atlantic (Overbeck, 1933) At this time, therefore, the sea appears to have reached approximately the present level.

From the middle Atlantic onwards, the records of the movements of the sea-level are considerably more detailed, as shown above in the list of the strata of Wiggenhall St. Germans. There were a number of minor fluctuations, confirmed by Godwin and

other workers in a good many localities. After a slow rising or even a stagnation of the sea-level during the middle Atlantic (Neolithic) at about — 24 feet. (— 7 metres), the sea began to rise rapidly during zone VII*c* (late Atlantic or early Subboreal, Bronze Age) to about two feet *above* the present sea-level. The fen clays and other inundation clays were formed during this transgression. Soon after, however, the sea-level appears to have dropped again, since erosion channels were cut into the fen clay. Godwin estimates this drop, on the evidence obtained by Swinnerton (1931) at Ingoldmells, Lincolnshire, at 12 to 15 feet. Climatically, this low level corresponds to the early part of the transitional zone VII–VIII (late Subboreal; late Bronze Age and Hallstatt periods). A second rapid transgression followed at the end of the transitional zone VII–VIII (Iron Age, beginning of Christian era) up to 5 to 10 feet above the present water level. Another clay deposit, the *Scrobicularia* Clay, was formed. Since that time, the sea-level has, according to Godwin, dropped again to — 7 to 8 feet (about A.D. 700) and finally risen to its present height. This last oscillation is confirmed by an interesting observation made by G. Fowler (communicated in Godwin, 1940*a*, pp. 295–6). He found that, during the last 900 years the sea-walls at the mouths of the Fenland rivers have been built on successively higher levels.

Essex coast. Further evidence of Postglacial fluctuations of the sea-level around the British coasts has been discovered and studied near Swansea in South Wales, on the coasts of Essex, and in Bideford Bay, North Devon. The Swansea site (Godwin, 1940*c*) illustrates the transgression during the Boreal. Since South Wales is within the zone which suffered isostatic re-adjustment, it is not discussed here.

On the coast of Essex, two large areas of Neolithic and Bronze Age occupation sites occur at Clacton-on-Sea and Walton-on-the-Naze, respectively. They have been investigated, among other workers, by S. H. Warren who for many years has concentrated his attention on the sites at Clacton. A report, which includes the Walton site, was published by Warren, Piggott, Clark, Burkitt and Godwin in 1936, and since then the present author has been able to continue observations at the latter locality, thanks to facilities most kindly afforded by Mr. Miles C. Burkitt.

Walton-on-the-Naze. The site at Walton lies on a peninsula called the Naze which extends from the town northwards between the sea and the submerged river system of Hamford Water and Walton Backwater. It is made up (fig. 35) chiefly of Red Crag and London Clay and capped by a brown weathering layer. The northern half of this peninsula is marshland at the seaward edge of which the Postglacial deposits are exposed over a length of about 2 miles at low tide. As the surface of the Naze core slopes down

towards the marshland, the brown weathering layer comes down also and finally dips beneath the present sea-level, where it is covered by *Scrobicularia* Clay. This weathering layer is the 'rainwash' of the reports; it represents the soil of a phase when the sea-level was lower than to-day. It continues to dip in a northward direction, towards the mouth of the drowned river system of Hamford Water and disappears below the low-water mark. The localities 1 and 2 of the report (Warren and others, 1936), therefore, which are close to the old London Clay core, show the most complete succession of deposits (fig. 35), from top to bottom, as follows:

F. Recent salt-marsh, destroyed by wave action to the seaward of the sandy beach ridge which is advancing over the marsh.

E. *Scrobicularia* Clay. This clay attains a thickness of at least 10 feet and reaches up to about 2 or 3 feet below high-water mark. Since *Scrobicularia* is considered unable to live above low-

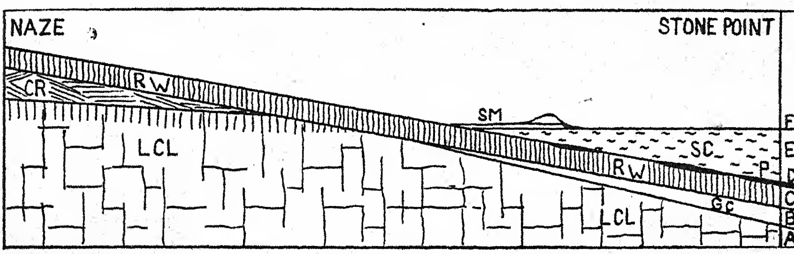


FIG. 35.—Section from the Naze to Stone Point, Walton-on-the-Naze, Essex. Right-hand column: lettering as in text. LCL: Eocene London Clay, top weathered in the Naze. CR: Crag, lower Pleistocene. GC: Light grey clay. RW: Rainwash. P: Peat and occupation level. SC: Scrobicularia Clay. SM: Salt marsh and sandy beach-ridge.

water mark, it is likely that this clay indicates a rise of sea-level to about 8 to 9 feet above O.D., the tidal range at this locality being about 11 feet. This figure agrees well with that of + 5 to 10 feet found by Godwin for the *Scrobicularia* Clay of the Fenland at Ingoldmells.

D. The "peat', which is absent over wide areas and is nowhere more than a few inches thick, is really a peaty marsh-clay. Godwin found from the pollen contents that it developed in a brakish water zone over a salt marsh. The tree pollen was so scarce that neither here nor in the corresponding deposit at Clacton satisfactory countings could be carried out. Godwin found, however, that beech was present and concludes that the peat is not likely to be earlier than Bronze Age.

C. The occupation level is marked by a brown weathering horizon of the underlying deposits. This weathering horizon is locally absent, however, and was probably sometimes removed by

8

man. The top few inches are frequently blackened, as a result of human occupation, and it is difficult to decide whether peat (D) is definitely later than this occupation horizon, or more or less contemporary with it. Cooking holes were cut into the brown weathering horizon. It is remarkable that potboilers, flints and sherds occur also down to about one foot in the brown weathering horizon. This is likely to be due to disturbances in the soil as they are normally connected with human occupation.

Apart from derived Lower Palaeolithic, and some possibly Mesolithic, patinated flints found in the weathering layer, all flints and sherds found here as well as at Clacton belong to the Lower Halstow Culture (few specimens), Neolithic A (Windmill Hill, plenty), Neolithic B (few), grooved ware Neolithic, and Beaker B (Bronze Age, few). No other Bronze Age types have been recorded.

Wooden structures which may have been huts have been mentioned repeatedly by Warren and Burkitt. One such structure was visible in June 1937. Between the upright poles there was what appeared to be a layer of wattle, and the ground around the structure was strewn with potboilers, round flint pebbles, and cockle shells, but no datable flint implements or sherds were found. The age of this and similar structures is limited by (*a*) their erection on the weathering surface of (C), and (*b*) by the *Scrobicularia* Clay covering them. They may be contemporary with the Neolithic-Bronze Age occupation, or later.

The hut just described is of particular interest since it stands close to an ancient water course whose flanks are covered with plant stalks (probably some kind of reed). This water course was once filled with and covered in by *Scrobicularia* Clay and is, therefore, older than this deposit, though in recent times the sea, having washed away most of this clay, uses the channel again, as a tidal creek. Similar water courses have been described by Warren from Clacton. This author is inclined to regard them as artificial. He brings forward evidence for their contemporaneity with the Neolithic-Beaker occupation, no implements other than Neolithic or Beaker having been found in them.

B. Underneath the brown weathering horizon (C), a light grey clay is observed (greenish clay as described by Burkitt). Burkitt noticed that this clay differs from the underlying London Clay in being softer, and that there is a layer of marine shells at its base. He suggests that the clay may be estuarine. My own observations point in the same direction. I found *Cardium edule* L. in the clay. In view of the possible importance of this deposit, however, more definite evidence of its origin is desirable.

A. London Clay, solid and typical.

The succession of Walton has been given here in detail since it differs to some extent from the succession observed by Godwin in

the Fenland. Godwin found evidence that the sea-level had risen to about − 20 feet in the late Neolithic, and that it exceeded the present level twice thereafter, in the early Bronze Age (+ 2 feet) and in the Iron Age (+ 5 to 10 feet). At Walton, the apparently estuarine clay (B) suggests a sea-level at least as high as the present one, *ante*dating the Neolithic, and there also is definite proof of one sea-level of about + 8 to 9 feet after the Bronze Age. The latter is probably the later of the two transgressions of the Fenland. Evidence for the earlier is still missing.

Bideford Bay. At Westward Ho, on Bideford Bay in North Devon, another Postglacial sequence is exposed, which appears to provide evidence that the fluctuations observed in the Fenland apply to the west of England also. Moreover, the pre-Neolithic high sea-level indicated at Walton seems to be confirmed in Bideford Bay. An investigation of this site, carried out jointly by Mr. E. H. Rogers of Torquay and the present author, is under way. So far, a preliminary note has been published by Mr. Rogers (1942).

Fluctuations in the Postglacial Transgression. Godwin's three high sea-levels are about 1,800 to 2,000 years distant from one another. If the pre-Neolithic high level can be further substantiated, it seems that, on the whole, the Postglacial transgression proceeded in a fluctuating manner. It may be well worth while to consider these fluctuations in detail when more evidence has become available and to see whether or not they can be correlated with one of the astronomical, climatic or geological cycles of medium length.

The opening of the English Channel. The question of the opening of the English Channel in Postglacial times is intimately connected with the fluctuations of the sea-level. There is a wide-spread misconception that the Chalk ridge which once may have extended from Dover to Calais was not breached until after the Last Glaciation, the separation of Britain from the Continent being effected in this manner and at such a late date.

In fact, the Chalk ridge must have been breached at an earlier date. It has been pointed out by Reid (1913) and other workers that, during the two maximum glaciations (Penultimate and Antepenultimate Glaciations), the meltwater of the ice, together with the waters of the Thames and the Rhine, is likely to have drained through the Straits of Dover. This implies that there was a gap or that a gap was eroded by these waters.

Moreover, interglacial beach deposits of the Monastirian phase (see p. 128), of the Last Interglacial, are found on the French side of the Straits to the east of Calais, round the corner where the Flandrian plains begin. This supports the view that the Straits were a sea channel during the Last Interglacial. It is further strengthened by the occurrence in the Eem deposits of the North Sea of the Last Interglacial of many mollusca commonly regarded

as members of the Lusitanian fauna. Such forms, which are sensitive to cold water, are more likely to have entered the North Sea through the English Channel than around the northern tip of Scotland.

There is plenty of evidence that wave action, intensified by tidal scour, has widened the gap between Dover and Cape Gris Nez since it became flooded in Postglacial times. It is likely, therefore, that during the Last Interglacial the Straits were narrower than they are now.

The present conditions in the Straits are such that a drop in sea-level of about 40 metres would produce a broad and uninterrupted connexion of Britain with the Continent (for figure, see Fox, 1938, p. 25). Since the sea-level is considered to have receded to − 100 metres during the Last Glaciation, it is evident that, in spite of the greater age of the gap in the Chalk ridge and in spite of its submergence during the Last Interglacial, a land bridge existed during the Last Glaciation, and presumably for some considerable time afterwards.

The question as to the date of the Postglacial re-opening of the Straits of Dover, therefore, should be formulated more precisely: At which date was the flat floor of the gap in the Chalk ridge flooded when the sea-level rose in Postglacial times? It is comparatively easy to answer if only an approximate date is required. In the Dogger Bank area, the − 40 metres level was submerged in early Boreal times, about 7000 B.C. Provided the floor of the Straits was not covered with thicker deposits than it is now, the sea may have flooded it at about this time from the west. This is the earliest possible date for the Postglacial separation.

If however there were on the floor of the Straits deposits which have since been removed by tidal scour, and it is quite likely that there were some, the submergence of the floor of the Straits may have occurred at a somewhat later date.

The upper time limit is given by the completion of the Postglacial transgression. In north-west Germany, the present level was reached by the end of the Boreal or the beginning of the Atlantic, roughly at about 5500 B.C., and by this time the separation of Britain from the Continent would have been completed (Zeuner, 1935; Stamp, 1936). British evidence suggests that, in southern England the subsidence continued with oscillations into the Subboreal (Beaker period; Godwin, 1940*a*).

In view of the significance of the precise date of the separation of Britain from the Continent, the limits obtained in this way, i.e. between 7000 and 5500 B.C., are unsatisfactorily wide. The early Boreal was the time of the pine-hazel woods and of the Mesolithic industry, whilst at the beginning of the Atlantic the Mixed Oak Forest was established and the Mesolithic was beginning to give way to the early Neolithic.

Recent evidence has tended to favour an early date within the above limits. Ullyott (1936) used the present distribution on both sides of the Channel of flatworms with definite climatic requirements in order to show that 'the freshwater connexion between England and the continent was severed before the [summer] temperature had risen to 16° C.' Since a land connexion may have persisted somewhat longer than a connexion of the freshwater systems, the date of the marine submergence may be slightly later. Clark (1936*b*) points out that Ullyott's evidence places the severance well within the Boreal phase, 'before its later stages when the temperature curve rose to its maximum during Postglacial time'. Clark finds such an earlier date further substantiated by the absence from Britain of certain Danish late Maglemose types of implements, which indicates that a break in cultural relations had taken place by that time. In this manner, a date between 6000 and 7000 B.C. for the separation can be supported.

Advocates of a later separation, on the whole, accept the geological and palaeobotanical evidence, but adduce archaeological evidence suggesting that the Straits of Dover were still either very narrow, or dry land, when the immigration of the Neolithic 'A' people took place. This view is held, for instance, by Fox (1938) who argues that the sea-route through the English Channel and the North Sea to reach Scandinavia and the Baltic was hardly used at all by Neolithic man, and that he preferred the northern route round the north of Scotland. Fox suggests 5000 B.C. as a date for the separation but thinks that the Channel remained narrow and shallow right into the third millenium B.C., on the one hand preventing Megalithic man from using the dangerous North Sea route with its shoals and strong tides, and on the other hand enabling inland folk such as the Neolithic 'A' people to ferry across the narrow Straits and reach Britain in calm weather.

Peake (1938*a*, *b*) goes much further than Fox in stressing the latter point. In his view, the Neolithic 'A' people could not even have ferried their cattle across to England, and this would tend 'to indicate that the Kent-Artois ridge was not breached until close on 2000 B.C.' Since, however, geology suggests that the breaching of the Chalk ridge took place before the Last Glaciation, so that only low-lying marshes and dunes would have been submerged when the sea broke through in Postglacial times, Peake's argument stands and falls with the question whether the cattle was driven overland or ferried across a narrow strip of water. The extremely late date favoured by Peake, therefore, has practically no chances of being substantiated. Fox's argument concerning the scantiness of evidence for the Neolithic sea-route through the Straits is more serious; he suggests himself that strong tides and the dangers of the shallow North Sea may have acted as a deterrent, so that his theory does

not contradict, but merely elaborate, the theory of the earlier break-through.

It would appear, therefore, that the separation of Britain from the Continent actually occurred in Boreal times, between 6000 and 7000 B.C., and that the widening of the gap was a gradual process, so that immigration into Britain became increasingly difficult as time went on.

Ireland. In Ireland (fig. 36), the climatic changes during the late Glacial and Postglacial times have recently been investigated by a number of authors, among them the members of the Harvard Irish Survey, in co-operation with K. Jessen (Copenhagen).

Cushendun, Co. Antrim. The most typical site is at Cushendun, Co. Antrim, in the north-east of Ireland. Here, beach deposits reach up to 36 feet above O.D. Since north-east Ireland is inside the area of isostatic re-adjustment, the high position of this Postglacial beach formation is not surprising. The thickness of the excavated deposits is about 9 metres.

The site was studied by Burchell (1931), and afterwards by the Harvard Irish Survey (Movius, 1942). Jessen (1940) established the pollen-analytical sequence. The section is composed of the following strata:

(A) Weathered top stratum, formed since Late Atlantic. With Neolithic industry.

(B) Upper beach gravel. With rolled implements of the late Larnian.

(C) Upper lagoon silt. Jessen's Irish zone V*b*, Atlantic. No implements.

(D) Lower beach gravel. Early Atlantic. With early Larnian.

(E) Lower lagoon silt, with abundant marine fauna, including the somewhat southern bivalve shell *Paphia decussata* (L.). Pollen-analytically lower part of V*b*, transition from late Boreal to early Atlantic, with early Larnian industry.

(F) Swamp peat. Also early part of zone V*b*, transition from Boreal to Atlantic.

(G) Re-sorted boulder clay, formed previous to the Litorina Transgression. No artefacts.

(H) Laminated clay. Glacial.

(L) Boulder clay. Glacial.

This section shows that, in northern Ireland, the Mesolithic, of which the Larnian forms a variety, lasted well into Atlantic times. Movius (1942) who has made a special study of the Larnian industry regards it as the descendant of the British upper Palaeolithic. Burchell (1931) even regards it as late Magdalenian. Movius concludes: 'Thus, at the time of the Al'Ubaid culture in Mesopotamia, Ireland was still virtually in an evolved Upper Palaeolithic stage of development.'

TENTATIVE DATES (BASED ON DE GEER)	PERIODS	GLACIAL ERAS	LAND MOVEMENT	BALTIC	NORTH SEA	IRISH SEA	SCOTLAND	CLIMATIC PHASES	ZONES	FOREST DEVELOPMENT IN IRELAND (K. JESSEN)	FAUNA (IRELAND + SCOTLAND)	ARCHAEOLOGICAL REMAINS IN NORTH-EAST IRELAND
B.C.	POST-GLACIAL		EMERGENCE	CONDITIONS AS AT PRESENT				SUB-BOREAL Cold and Dry–Continental Climate	VI	Pine curve stops	Domestic Animals introduced	Earliest Megaliths Western Neolithic Culture Start of the Campignian Industrial Development. The EPI–MESOLITHIC Bann and Sand Hill Cultures.
2,500	POST-GLACIAL		SUBMERGENCE	LITORINA SEA	TRANSGRESSION OF THE NORTH SEA BED	LITORINA RAISED BEACHES Submerged Gravel and Marine Clay Deposits Caves formed at Oban and Elsewhere TRANSGRESSION OF THE IRISH SEA BED Invasion of Valleys by the Sea	Scotland Separate from England except for a narrow Isthmus	Cooler at End Climatic Optimum ATLANTIC Warm and Moist: Oceanic Climate	VI VIb UPPER	Alder dominant Oak, Elm, Pine and Birch Hazel comparatively rare Alder curve starts Pine: 2 maxima Alder – traces only Oak dominant over Elm Hazel diminishing	Red Deer Wild Boar Aurochs Wolf Bear (?) Beaver Reindeer – survived Irish Elk – absent	MESOLITHIC IMPLEMENTS IN SECONDARY POSITION LATE LARNIAN: Curran Point, Larne Island Magee (Horizons 2+3) Glenarm (Horizon 1) Cushendun (Horizon 3) EARLY LARNIAN: Cushendun (Horizons 1+2) Island Magee (Horizon 1) Rough Island (Horizon 1)
5,600	EARLY POST-GLACIAL		EMERGENCE	ANCYLUS LAKE	MOORLOG FORMING Direct Land Connection between Britain and the Continent	SUBMERGED PEATS FORMING Partial Land-Bridge between Britain and Ireland		LATE: Warmer at End BOREAL EARLY: Cold and Dry: Continental Climate	VIb LOWER Va	Hazel maximum Elm dominant over Oak Pine curve rising Hazel curve starts Birch and Willow comparatively rare Pine increasing	Forest Forms: Irish Elk and Reindeer – survived Lemming – absent	EARLY LARNIAN: (*IN SITU*) Lough Neagh, near Toomebridge Archaeological Material
6,800	EARLY POST-GLACIAL	RAGUNDA: FINAL STADIUM FINIGLACIAL PERIOD 3RD RETREAT						PRE-BOREAL Gradual then rapid rise in Temperature	IV	Birch dominant Pine and Willow common	Mixed Tundra and Forest Forms Lemming (?)	Unknown
7,800	LATE-GLACIAL	FENNOSCANDIAN MORAINES VALLEY GLACIATION	SUBMERGENCE	YOLDIA SEA LATE GLACIAL SEA OUTSIDE THE BALTIC	LATE-GLACIAL SEA			ARCTIC (UPPER DRYAS PERIOD)	III	SOLIFLUCTION EARTH	Tundra Forms: Reindeer Bear Irish Elk Arctic Fox Lemming Wolf Lynx	No Existing Evidence of Occupation
8,300	LATE-GLACIAL	GOTIGLACIAL PERIOD 2ND RETREAT	SUBMERGENCE	BALTIC ICE-LAKE				SUB-ARCTIC (ALLERØD PERIOD)	II	ALLERØD DEPOSITS		
14,000	LATE-GLACIAL	POMERANIAN STAGE SCOTTISH READVANCE, ETC. DANIGLACIAL PERIOD 1ST RETREAT		ICE RECEDING FROM SEA BEDS				ARCTIC (EARLY DRYAS PERIOD)	I	SOLIFLUCTION EARTH		
	LATE-GLACIAL	MAXIMUM ADVANCE		COVERED WITH ICE	PARTIALLY COVERED WITH ICE		COVERED WITH ICE					

FIG. 36.—Late Glacial and Postglacial chronology of Ireland according to Movius (1940).

Alleröd Oscillation in Ireland. The Alleröd Oscillation is well established for Ireland. In one of the bogs at Ballybetagh, near Dublin, Farrington and Jessen (1938) found that two periods of solifluction (zones I and III), which appear at the bottom of the section, are separated by a mud with birch, willow, juniper, pine and other plants (zone II). The layer has yielded also remains of *Calathus fuscipes* (Goeze) (= *Calathus cisteloides* (Panzer)), a beetle of wide distribution in Europe which, however, does not go farther north than 63½° in Norway, 60° in Sweden, 60½° in Finland, and 62° in north-west Russia.[1] This form illustrates fairly well the kind of northern forest that grew at Ballybetagh at that time.

Similar successions have been found by Farrington and Jessen (1938) in three other Irish bogs and also on the Isle of Man, and Mitchell (1941) found it in one further Irish bog. The correlation of the Irish zones I, II, III with the Danish Early Dryas, Alleröd and Late Dryas zones, therefore, is very tempting, especially since in both areas the Preboreal conditions set in only above zone III. Jessen (in Farrington and Jessen, 1938), therefore holds the view that zone II corresponds to the Alleröd Oscillation of Denmark.

The Irish zones V to VI are not identical with those of either England or Denmark. Zone IV, the Preboreal birch-pine zone, appears to be the same in all three areas, but the subdivisions of V in Ireland cover, unfortunately, V, VI and lower VII of England (see fig. 28). The transition from Boreal to Atlantic is placed by Jessen (1940) in V*b*, at the decline of the hazel from its maximum, so that lower V*b* equals the late Boreal, and upper V*b* the early Atlantic. Difficulties arise in the higher zones, because of the delayed immigration into Ireland of certain trees. (See also note (6), p. 388)

On top of zone VI (Atlantic + Subboreal), a grenzhorizont occurs in Ireland, as it does in north-west Germany and southern Scandinavia. It falls between the middle and late Bronze Ages in Ireland. Zone VII is the Subatlantic, corresponding to zone VIII of Godwin in England.

G. LATE GLACIAL AND POSTGLACIAL (MESOLITHIC TO IRON AGE) CHRONOLOGY

Events on which a chronological system can be based. The preceding regional survey, incomplete though it is, shows clearly that the successions observed in the various areas resemble one another to a great extent, but they are not identical. They all agree on the general succession of glacial or solifluction deposits, tree-less tundra, birch-pine forests, a transitional phase with dominance of hazel, mixed oak forests, and finally beech forests (in those areas which

[1] It is not admissible, therefore, to call this beetle a ' southern ' form, as done by Movius (1940, p. 12).

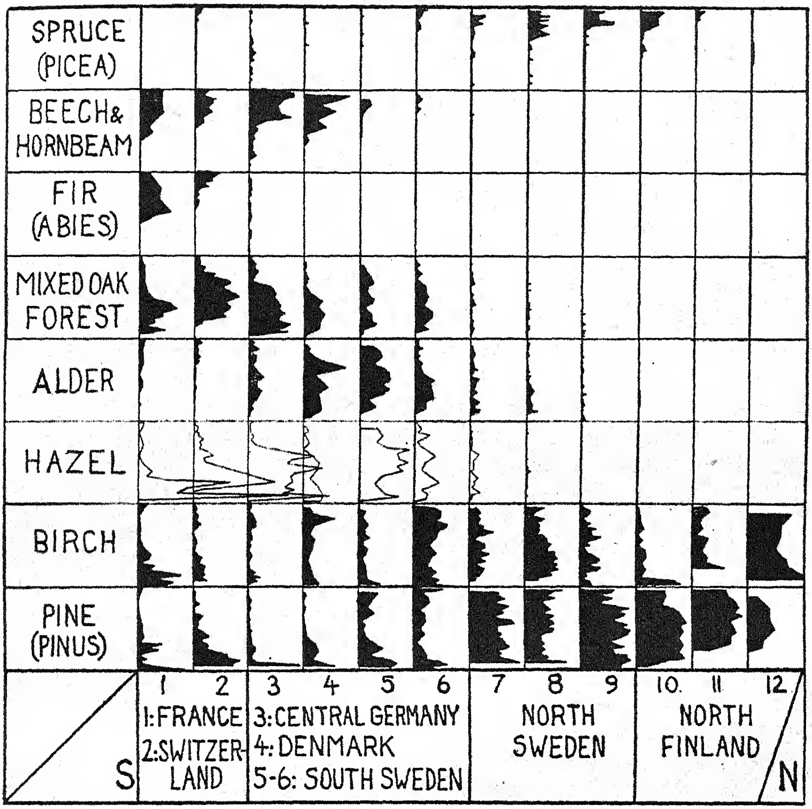


FIG. 37.—Synthetic Diagram of the development of the forests in different regions of temperate Europe, illustrated by localities arranged in a direction from south to north.

(1) Auvergne, 1,200 metres : (2) Bern, Switzerland, 524 metres ; (3) Vogelsberg, south-west Germany ; (4) Copenhagen ; (5) central Scania ; (6) Borås, south Sweden ; (7) Krylbo, north Sweden ; (8) Sollefteå, north Sweden ; (9) Kulbäcksliden, north Sweden ; (10) Kuusamo, Finland ; (11) Muonionniska, Finland ; (12) Kilpisjärvi, Finland.

The kinds of pollen are shown separately. In each unit, time proceeds in an upward direction. Each vertical column shows the composition of the pollen diagrams of one locality, whilst the horizontal columns demonstrate the changes in the frequency of certain kinds of pollen due to geographical factors. The diagram thus illustrates the geographical variation in the development of the Postglacial flora in different parts of temperate Europe.—After von Post (1929*b*).

were reached by the beech.[1] One can add that at the beginning of the floral succession, an alternation of tundra, birch-pine, tundra, birch-pine (or some equivalent duplication) is observed in so many areas of the belt surrounding the Scandinavian Glaciation, that this also has to be regarded as part of the general succession (figs. 30, 36).

[1] For general summaries, see Firbas, 1939 (continental Europe), and Godwin, 1941 (Britain), and figs. 30, 37, 38.

In attempting to employ this succession in the construction of a chronological system, two complications enter the picture.

(1) In an area extending from Finland to the British Isles and to Lake Constance, and adjoining a waning ice-sheet, there must have existed a distinct climatic zonation, from S to N (approaching the ice) as well as from W to E (increasing continentality). It cannot be expected, therefore, that all localities passed through the same floral phase at the same time. In particular, south-west Germany must have been considerably in advance of the more northerly regions at all times. Bertsch (1935) makes a point of this difficulty. It renders it impossible to arrive at a precise correlation of two distant localities by merely determining the phase of forest development.

(2) The second difficulty is that of the varying rates of spreading of the species. Again it was Bertsch (1935) who studied it in detail. He elaborated the example of the beech (p. 87, fig. 32) which spread at a much faster rate along the rivers than it did away from the rivers, and on the whole spread more slowly than other species. It is evident that the method and the rate of spreading determine in part the time of its arrival at a certain place. The constitution of the flora of any one locality, therefore, is influenced by this factor, though to a degree which is as yet hardly determinable.

In view of these difficulties it is necessary to look for some kind of 'land-mark' in the successions, which can be identified in a large number of sections and is of a sufficiently unique character to be used as a reasonably precise chronological datum. The chief requirement is, of course, that it was produced by an event which occurred simultaneously over the entire area considered.

There are two conceivable geological 'land-marks' of this kind, the Litorina Transgression and the halt of the ice-recession at the Fennoscandian moraines, and three botanical ones: the Alleröd Oscillation, the Postglacial Climatic Optimum, and the Subboreal. The Alleröd Oscillation is closely connected with the halt at the Fennoscandian moraines; they are, therefore, discussed together.

Litorina Transgression, chronological significance. The Litorina Transgression would provide an excellent datum, had there not been superimposed on it isostatic movements. As it is, the maximum of this transgression was reached locally at different times, depending on the relative rates of rise of the sea-level and of the land. An encroachment of the sea upon the land could occur only where the rate of rise of sea-level was greater than that of the land; where the rate of rise of the land overtook that of the sea, as it appears to have happened in parts of Scandinavia, the maximum of the local transgression will be earlier than the actual maximum as far as it depends solely on the rise of the sea-level. The Litorina beach corresponding to the highest stand of this sea, therefore, cannot be contemporaneous

over the entire area. In fact, the 'Litorina Maximum' has been dated at about 5000 B.C. for Finland, 4500 B.C. for Gotland, and as late as the Atlantic (beginning of Passage Graves time, i.e. about 2400 B.C.) for Denmark (Troels-Smith, 1937). This retardation in the south, or rather the precocity of the maximum transgression in the north, is probably the result of the rapid isostatic rise of northern Scandinavia.

Alternatively, compensatory sinking of the land in the peripheral zone surrounding the area of isostatic uplift would retard the local maximum transgression. It may be that the observations of an advance of the sea in north Germany lasting into historical times, and the late date for the maximum sea-level in the Cambridgeshire Fens, about 0 B.C./A.D. (Godwin, 1940*a*) are due to this cause. It is evident, therefore, that the maximum of the Litorina Transgression cannot serve as a chronological land-mark for the entire area under consideration.

Fennoscandian moraines, chronological significance. The halt in the ice-recession documented by the formation of the Fennoscandian moraines (Middle Swedish and south Finnish moraines, Salpausselkä phase, p. 28) is the most marked event in the gradual disappearance of the ice-sheet of the Last Glaciation. The two or three parallel belts of terminal moraines have been dated by De Geer and Sauramo in Sweden and Finland at roughly 8600–7900 B.C. (see p. 32). Leaving aside the problem of the accuracy of these figures, it is considered possible, and by some probable, that this halt in the recession corresponded to a deterioration of the climate, which left its trace in the floral history. The pollen diagrams of southern Sweden (Nilsson, 1935) provide for only one correlation of this kind, namely with the deterioration which followed the relatively mild Alleröd phase.

On the assumption that this correlation is correct, a most valuable 'land-mark' becomes available which would date the second *Dryas* Time or its equivalent at about 8600 to 7900 B.C. in any section within the triangle Finland—Ireland—south-west Germany. The Alleröd deposits or their equivalents would fall slightly earlier, at about 9000 B.C. or somewhat more. Thus a valuable guide for the dating of the Mesolithic has been obtained.

Postglacial Climatic Optimum, chronological significance. Unfortunately, the Alleröd Oscillation is too early to help in dating the transition from the Mesolithic to the Neolithic, and any later cultural phase. For these later times, the Postglacial Climatic Optimum and the supposed dry phase of the Subboreal may be considered as possible 'land-marks'.

The Postglacial Climatic Optimum (see p. 59), however, is rather difficult to define. There is abundant evidence that for some time during the Postglacial, conditions of life for certain plants were

more favourable than they are at present, and it may be added that the same applies to marine shells, as was first pointed out by Praeger (1892). The genial period may have been one with a more continental climate, i.e. with hotter summers, permitting plants which prefer this type of climate to advance northwards. Or it was the annual average temperature that was higher than now. The palaeobotanical evidence suggests that in late Boreal times the former interpretation applies, and that during the Atlantic, when the climate had become decidedly oceanic, the average temperature was, for a while, higher than at present. Clearly, a period which is so vaguely defined and spread over a great part of the floral succession (earliest stage suggested, late Boreal; latest, Subboreal; majority of opinion, Atlantic) is not suitable to serve as a chronological 'land-mark' for the correlation of different areas.

Subboreal 'dry' phase, chronological significance. Similar difficulties prevail as regards the Subboreal (see p. 64). At one time it was considered as a clearly marked dry phase of short duration (Gams and Nordhagen, 1923), largely under the influence of Weber's Grenzhorizont, but later workers found it difficult to define the beginning of this phase, and some even began to doubt its dry character altogether. It developed so gradually from the typical Atlantic, and the Mixed Oak Forest was certainly not replaced by constituents fond of drier conditions, that the chief evidence for a dry Subboreal remains the layers of tree-stumps in bogs, the extension of forest growth to a higher altitude than at present, and the subsequent covering of these witnesses of forest by the Subatlantic, definitely damp, *Sphagnum* peat. In the bogs, even where there is no layer of tree-stumps, the type of peat changes abruptly, and the resulting unconformity is called the Grenzhorizont (p. 64). This horizon, however, has been interpreted in a variety of ways, even as evidence for drowning instead of drying of the bog, and in some areas more than one Grenzhorizont is observed.

Godwin (1941) sums up the present position regarding the Subboreal as follows:

> Such forest layers are thus linked with the 'Grenzhorizont' as expression of the dry period just before the Subatlantic climatic deterioration. What remains impossible is any indication of the *onset* of such a dry period, or indeed of the recognition of any period which can be clearly said to correspond with the Subboreal of Blytt and Sernander. Though indications of dryness exist, then, as we have already seen, more recurrence surfaces [1] than one may be found, and we are inclined to think of all the lower *Sphagnum* peat as indicative of dryness. The question of the Subboreal, in Britain, and the climatic changes in the long period between zones VI and VIII, is one for which present evidence is quite inadequate, but which evidently demands investigation.

[1] I.e. grenzhorizonts.

For the time being, therefore, the Subboreal cannot be used as a 'land-mark' in chronological correlation.

Absolute chronology of the late Glacial and Postglacial. It must be admitted, then, that the absolute chronology of the time which has elapsed since the maximum of the Last Glaciation, and of the prehistoric industries of this period, relies on somewhat scanty evidence. The relative chronology, as based on the correlation of climatic phases and the oscillations of the sea-level, suffers from the lack of complete contemporaneity, as described in the preceding paragraphs, and if one places the chronologies of Finland, Gotland, South Sweden, Denmark, Britain, Ireland, north Germany and south Germany on one and the same time-scale, using the absolute dates suggested by local workers, one finds that certain discrepancies exist (figs. 30, 38). It has been pointed out that some of these indicate genuine differences of age, but others are most likely due to our insufficient system of relative chronology. The establishment of the Alleröd Oscillation as a chronological land-mark (provided its interpretation as the mild period preceding the halt of the Fennoscandian moraines is correct) will help in bringing the various chronologies somewhat into line.

The absolute dates suggested by De Geer and Sauramo for the Fennoscandian moraines thus attain the greatest importance as the zero-point of prehistoric chronology. All dates suggested for events from Subarctic times onwards have been based on these figures, or on others derived from them. If, however, one searches the literature for papers the main subject of which is chronology, and not local sequences of deposits, one finds very few. Although this represents the inevitable stage of random accumulation of material prevailing in any young branch of research, it is greatly desirable that some future work should be aimed deliberately at linking investigated peat sections or beach deposits with the varve chronology. At the present time, the absolute time-scale which workers apply to their relative successions is rarely discussed in their papers.

Nevertheless, it is possible to derive *approximate* figures for the ages and durations of prehistoric phases from the numerous local chronologies suggested. They are summarized here in a table (fig. 38), in which the three major areas of central Europe, Baltic, and the British Isles, are distinguished and compared with the Egyptian chronology as an example of a historical time-scale. The retardation of certain cultural phases in the N and NW compared with the SW is apparent. On the whole, the dates are not unreasonable, considering the slender basis they have. Future chronological work will, no doubt, modify them; in particular, the changes from Palaeolithic to Mesolithic, and from Mesolithic to Neolithic, require special attention.

Attempts at astronomical dating. In view of the difficulties implied in varve chronology, some workers on the Postglacial have

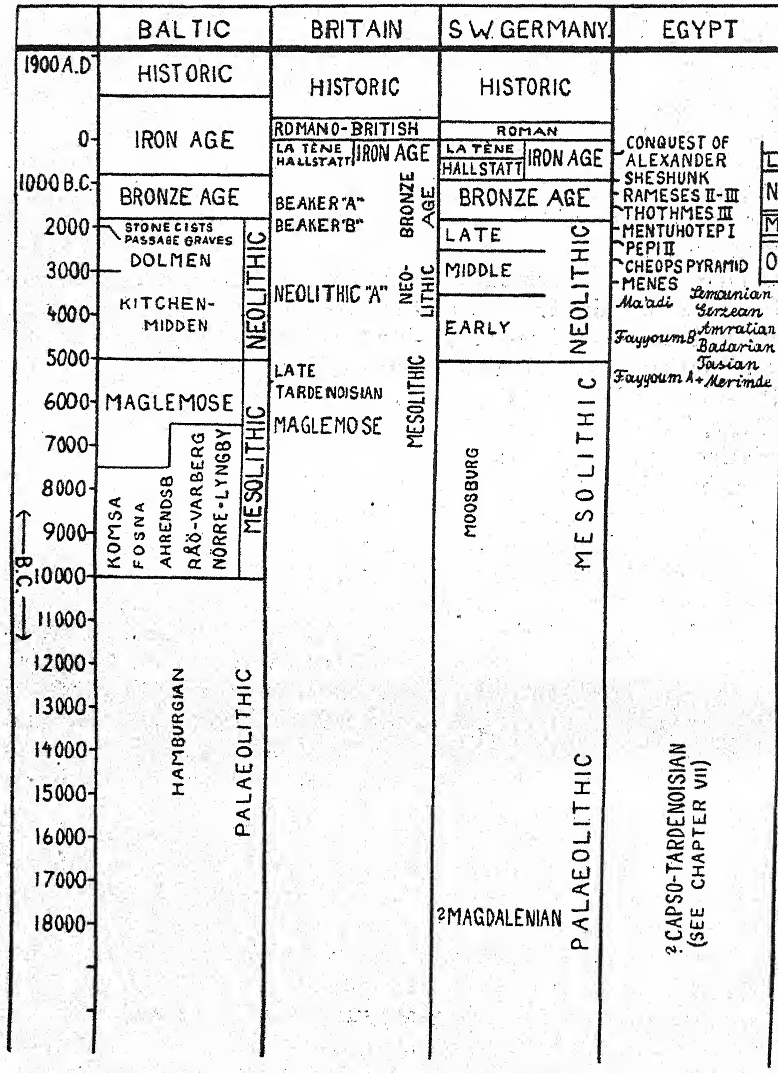


FIG. 38.—Absolute chronology and correlation of the human cultures of the Baltic, Britain and Germany, as based on geological and botanical evidence. For comparison, the historical chronology of Egypt (kindly supplied by Professor S. R. K. Glanville) has been added. The discordances between the four chronologies have *not* been smoothed out. *Italics:* Chronological position estimated by S. A. Huzayyin (1941). L: Late Egyptian Period; N: New Kingdom; M: Middle Kingdom; O: Old Kingdom.

attempted to apply the fluctuations of solar radiation as calculated from the perturbations of the earth's orbit (see Chapter V) to the succession of climatic phases of the Postglacial (Hyyppää, Gross, Bertsch, Rust, etc.). The results of these various attempts are still conflicting with one another.

PART III

DATING THE OLD STONE AGE, THE PHASES OF THE ICE AGE AND THE PLUVIAL PHASES OF THE WARMER COUNTRIES

(Back to about one million years ago)

CHAPTER V

THE RELATIVE AND ABSOLUTE CHRONOLOGY OF THE PLEISTOCENE

As in the chronology of the late Glacial and Post-glacial, so in that of the Pleistocene, a relative, climatic, chronology has to be developed in the first instance, in order to serve as the basis of reference for the events to be dated. The late Glacial and Post-glacial relative chronology was supplied by the changes the climate underwent between the climax of the last glacial phase and the present day, and it was derived mainly from palaeobotanical evidence; in the Pleistocene, the relative chronology is provided by the succession of glacial and interglacial phases, and it relies mainly on alternating geological processes of deposition and destruction of deposits.

In either case, the absolute chronology has been developed independently of the relative chronology, in reliance on some kind of astronomical rhythm, namely the year in the late Glacial and Postglacial chronology and the perturbations of the earth's orbit in Pleistocene chronology. It is necessary to keep in mind that, in either case, the absolute chronology is attached to the relative (climatic) chronology by comparatively few links, and that the relative chronology has not been made in order to suit the time-scale provided by the absolute chronology. The justification for the use of the latter as a time-scale consists in a number of coincidences which are difficult to explain as pure chance. If anybody regards the application of the absolute time-scale as unconvincing, it is open to him to discard this part of the Pleistocene chronology altogether. That, however, will not affect the value of the relative, climatic, chronology. In order to emphasize this distinction between the relative chronology, i.e. the succession of climatic phases as established on geological evidence, and the absolute chronology, i.e. the time-scale as deduced from the astronomical theory of the Pleistocene climate, they are discussed in two separate parts of this chapter. These parts are followed by a third which gives the links between the two.

A. THE SUCCESSION OF CLIMATIC PHASES DURING THE PLEISTOCENE [1]

Glaciations and interglacials. Ever since it was discovered that during the Pleistocene large portions of temperate Europe were covered with sheets of ice emanating from Scandinavia, Scotland, and the Alps, evidence has been brought forward that the process of glaciation was repeated several times. The actual number of glaciations, however, was not easily ascertained since later glaciations were liable to destroy or veil the deposits of earlier ones. Moreover, it is as a rule impossible to distinguish as products of different glaciations two superimposed glacial deposits (such as boulder clays or bottom moraines; or glacifluvial or meltwater gravels) unless a weathering horizon intervenes.

Superposition of glacial and interglacial deposits. Investigators, therefore, have attempted to recognize phases in the peripheral zones of the ice-sheets rather than in the central ones. Here, interglacial deposits are more likely to be covered by bottom moraine of the advancing ice-sheets, without being destroyed completely. On the whole this work has not been very successful. Though interesting interglacial deposits, containing temperate faunas and floras, were discovered, the local succession rarely fulfilled the requirement of proving that more than one interglacial had occurred. Borings were more successful in this respect, a few in North Germany having produced evidence for two interglacial phases separating three advances of the Scandinavian ice (Rüdersdorf, for instance, see Wahnschaffe and Schucht, 1921). Consequently, the view became generally accepted that the Scandinavian ice advanced and retreated three times. These three glaciations were called Elster (the earliest), Saale and Weichsel Glaciation.

Geomorphological method, meltwater deposits. A different approach to the problem is afforded by the belts of terminal moraines and meltwater deposits which mark successive halts of the ice. When, except for minor oscillations, the ice-margin became stabilized in a certain area, a zone of meltwater deposits (*glacifluvial* gravels and sands, clays and varved sediments) developed in front of it. If the country was flat, the glacifluvial deposits (pl. IX, fig. B) assumed the shape of cones radiating from the points of issue of subglacial water-courses (pl. IX, fig. A) or of sheets sloping away from the ice and fed by superficial meltwater. Such formations are called *sandr* (pl. X, fig. B). Their distant portions merge into river terraces, thus providing a link between the glacial phase and the level occupied

[1] This subject-matter is discussed in detail in Zeuner (1944). The present treatment is a summary of Chapters I to VI of the publication mentioned, to which the reader is referred for fuller information and bibliographical references. But many localities which have provided climatic and archaeological evidence are described in Chapters VI to VIII of the present book.

by the river at that time. On the periphery of the Scandinavian ice-sheet, wide valleys are observed, large portions of which are no longer used by major rivers and whose surface features and gradients betray that they functioned for comparatively short periods only and under a frost climate. These conspicuous valleys which run parallel to, and at some distance from, the ice-margins are called *urstromtäler*; sing. *urstromtal* (pl. VII, fig. C; pl. X, fig. A). They are of great interest since they enable us to reconstruct the hydrographical system of the glaciation (Zeuner and Schulz, 1931), and the subsequent development of the modern river system from it.

The bottoms of urstromtäler are often very sandy, and winds have heaped up the sand in dunes (pl. X, fig. A). Ancient dune fields are frequently met with, therefore, and the shape of the dunes makes it possible to deduce the prevalent direction of the wind, which was east in northern Germany (Solger, 1910). This has been taken as evidence for the existence of anticyclonic conditions over the Scandinavian ice-sheet.

Few urstromtäler were formed at the margin of the ice-sheet of the Alps, for here the general gradient of the surface is away from the ice, favouring radial river systems, while the Scandinavian ice moved up the gentle gradient from the Baltic Basin towards the mountains of Central Europe. The latter arrangement of course favours peripheral water-courses. The only area of the Alps where peripheral urstromtäler play an important role, is the basin of Lake Constance (Schmidle, 1914; pl. VII, fig. C).

Where the ice discharged its meltwater into river-valleys leading away from it, the sandr takes the form of an aggradation of gravels which, the river having since cut down again, now appears as a river terrace. Such glacifluvial terraces are common around the Alps. It is interesting to note, however, that the *early* Pleistocene gravel-sheets of the Alps are more of the ordinary sandr-type. By *late* Pleistocene times, the rivers had deepened their valleys sufficiently for glacifluvial river-terraces to become the dominant type.

Terminal moraines. The glacifluvial formations are of so much more general occurrence than terminal moraines, that they have been considered first. At the actual ice-margin, a *terminal moraine* is sometimes built up (pl. VII, figs. A, C; pl. VIII, fig. B), consisting of the load of rock-waste, sand and mud, carried by the ice (pl. VII, fig. B). Unless pressure is exerted, this debris left by the melting ice cannot be piled higher than the thickness of the ice; no conspicuous ridge is formed in this way, and the moraine is nothing but the edge or crest of the sloping sheet of the sandr. But if the ice margin oscillates and during the small advances actively pushes into these deposits, ridges of pressure-moraines are formed

which sometimes are most prominent geomorphological features. These terminal moraines are always recognizable by their internal structure, being composed of folded and distorted sandr material and boulder clay.

Glaciations of Scandinavian area. Returning to our chronological problem, it must now be stated that, while the analysis of the zones of moraines and sandrs of the Scandinavian Glaciation confirmed that there were at least three major glaciations, substantial evidence was brought forward in favour of a fourth glacial phase, intervening between the Saale and Weichsel Glaciations. It is called the Warthe Phase.

The objection may be raised that a succession of belts of terminal moraines and glacifluvial belts need not represent a succession of glaciations separated by interglacials, but merely successive halts in the retreat from the maximum of one very large glaciation. This objection does apply to certain moranic belts, such as that of the Frankfurt-Posen Phase, but there are usually means of deciding whether a prolonged interval with a withdrawal of the ice to the north was intercalated between two zones of terminal moraines.

First, the younger the moraine, the fresher and more complete will be the preservation of the morphological details, such as the small hills and pits which are so typical of formerly glaciated districts. If one moves outwards towards the periphery of the Scandinavian area of glaciation, one observes the freshest morphology in Sweden, but the features are almost as fresh in eastern Jutland, north Germany and northern Poland, until one reaches the line usually called the *Pomeranian* or *Baltic End-moraine.*

Outside this line, the morphological features are somewhat less distinct, and small elements like pits or *kettle-holes*; originally filled with ice (pl. VIII, fig. A) are rarer. This type of country extends to the *Brandenburg Moraine* of the Weichsel Glaciation.

Outside the Brandenburg Moraine, a great difference is noticeable, the glacial features of the landscape often having been destroyed by fluviatile erosion and denudation, and replaced by features dependent on the modern river-system. But the major glacial forms, like terminal moraines, are still identifiable. This type of country extends southwards and south-eastwards to the *Fläming Moraine,* the moraine of the Warthe Phase.

Outside this line, glacial features are very rarely preserved, and weathering and denudation have caused the disappearance of much of the evidence for the country ever having been glaciated. But erratic boulders and patches of boulder clay and glacifluvial gravel are still found. In this area, two moraines of different age have been distinguished, partly by the presence of two different types of boulder clay with different contents of

erratics,[1] and partly because they are occasionally separated by a horizon of weathering indicating an interglacial climate (see p. 123).

These two ground moraines are those of the Elster and Saale Glaciations. Their extension was, apparently, on the whole nearly the same, but in Holland and north-west Germany, Saale appears to have exceeded Elster, and the same applies to Russia (see Tesch, 1939; Woldstedt, 1929; Grahmann, 1928).

This is an instance of the application of statigraphical methods, and therefore an illustration of the second way of settling the question whether belts of terminal moraines represent independent glaciations or merely stages of retreat.

In the Berlin area, which lies inside the Brandenburg, but outside the Pomeranian Moraine, borings and sections have shown that two upper boulder clays are separated by a horizon with a cool-temperate fauna which must indicate at least a temporary retreat of the ice (the *Rixdorf Horizon*, Dietrich, 1932). The series of glacial deposits covering the Rixdorf Horizon cannot be later than the Brandenburg Moraine, or the Weichsel Phase. Consequently, the *under*lying complex of 40 metres of boulder clays and sand may well represent the Warthe Phase. That this complex is unlikely to date from any earlier glaciation is suggested by the fact that beneath it a typical interglacial deposit is found (the *Paludina Horizon*), which in turn rests on a succession of two older boulder clays separated by 20 metres of sand. Here, then, appears to be evidence, in one section, for the Elster and Saale Glaciations (the two lowermost boulder clays), an interglacial (Paludina Horizon), the Warthe Phase (boulder clay beneath Rixdorf Horizon), a cool-temperate oscillation (Rixdorf Horizon), and the Weichsel Phase (uppermost boulder clay and sand).

The separation of the Pomeranian as a distinct phase is suggested by sections in East Prussia (*Masurian Interstadial*, Hess von Wichdorff, 1915), where fossiliferous freshwater deposits rest on a boulder clay regarded as that of the Weichsel Phase and are covered by a thin bed of a more recent boulder clay. Fauna and flora, however, are of a subarctic character, so that the milder phase which intervened between Weichsel and Pomeranian appears to have been comparatively cold.

Climatic succession in the area of the Scandinavian Glaciation. The evidence for climatic phases obtainable in the area of the Scandinavian glaciation can thus be summarized as follows: [2]

[1] The distinction of moraines by means of the contents of *erratics* (boulders and pebbles carried by ice, often derived from a very localized source) has been elaborated by Milthers (1934) and Hesemann (1934). It is called *Geschiebezählung*; in English it is conveniently described as *stone-counts*.

[2] There are many problems involved in the establishment of this succession which the reader will find discussed in Zeuner (1944, Chapter II). In particular, it has not been fully ascertained whether the Warthe Phase is chronologically nearer to the Weichsel or the Saale Glaciation.

Local terminology	General terminology	
Pomerian Phase		Phase 2
Masurian Interstadial		Phase 2/3
Weichsel Phase (Brandenburg Moraine)	Last Glaciation	Phase 2
Rixdorf Interstadial		Phase 1/2
Warthe Phase (Fläming Moraine)		Phase 1
Interglacial (Paludina Horizon)	Last Interglacial	
Saale Glaciation	Penultimate Glaciation	
Interglacial, weathering and denudation	Penultimate Interglacial	
Elster Glaciation	Antepenultimate Glaciation	

Several noteworthy conclusions can now be drawn :—

(1) The last three glacial phases are separated by cool-temperate phases only, not by typical interglacials. They may therefore be regarded as three phases of one major glaciation. We shall henceforth distinguish such *glacial phases*, separated by *interstadials*, from the major *glaciations* (composed of glacial phases) which are separated by *interglacials*.

(2) The three last glacial phases constitute the *Last Glaciation*. In chronological order, we find that the *Last Interglacial* was that following the Saale Glaciation, that the Saale Glaciation may alternatively be called *Penultimate Glaciation*, the preceding interglacial the *Penultimate Interglacial*, and the Elster Glaciation, the *Antepenultimate Glaciation*.

(3) There is no evidence that this succession is complete. The fact that the Last Glaciation is divisible into three phases suggests that the earlier glaciations also may have been composite. The concentric arrangement of deposits and terminal moraines in the peripheral zone necessarily suppresses older, smaller phases, evidence for which, therefore, is not likely to be available in the area of the Scandinavian glaciations.

Glaciations of the Alps. Fortunately, the forelands of the Alps afford a better chance of studying the earlier phases, since their deposits are found on the hills and the slopes of the valleys of the foothill zone where, owing to the great amount of erosion and the radial arrangement of the major valleys, in connection with tectonic upheaval, the deposits in question are spread over a considerable vertical range. It is here, particularly in an area of upper Swabia north-east of Lake Constance, that Penck and Brückner (1909) established their now famous and almost too generally accepted scheme of divisions. They tested this scheme around the entire periphery of the Alps and found it applicable everywhere.

Penck and Brückner's four glaciations. Their scheme is based on glacifluvial gravels, not, as is often assumed, on terminal moraines. Beginning with the latest deposits, a *Low Terrace*, a *High Terrace*, a *Younger* and an *Older Deckenschotter* (gravel spread) are distinguished. Each of these is connected with morainic deposits, and the corresponding glaciations are called *Würm*, *Riss*, *Mindel* and *Günz*. Penck and Brückner (1909) also used the amount of erosion between these phases of aggradation, and the depth of the weathering of the gravels, in an attempt at determining the relative duration of the interglacials. They found that the Penultimate Interglacial was about four times as long as either of the two others; hence it has been called the *Great Interglacial*. We shall return to Penck and Brückner's estimate later (p. 143).

Phases of the Last Glaciation in the Alps. The same authors further recognized subdivisions of the Last Glaciation. They found that the belt of terminal moraines is often doubled. But in certain areas, more than two terminal moraines can be distinguished (in the Lake Constance area of the Rhine Glacier, for instance). Inside the mountain valleys, three halts were distinguished as *Bühl*, *Gschnitz* and *Daun*, but these and two mild oscillations (*Laufen* and *Achen*) have since been almost entirely abandoned, even by Penck, in view of the great local variation in the retreat and the consequent difficulty of correlating stages in different areas. The Bühl Stage has won some fame because Penck, Soergel, and others, correlated it with the Pomeranian Phase, but Woldstedt (1928*b*) has produced serious arguments against this view, Bühl being much too insignificant a stage to be comparable with the Pomeranian.

If one concentrates attention on the glacifluvial terraces coming from the moraines of the Würm Glaciation, one finds that three separate stages can be distinguished in the Rhine area as constituting the Low Terrace (Zeuner and Kimball, 1944). This confirms the threefold division of the Last Glaciation recognized in Switzerland (Hug in Lake Zürich area), in Upper Swabia (Eberl, 1930) and in Bavaria (Troll, 1925), although many details concerning the relative sizes of the three ice-sheets are still obscure.

Subdivisions of the earlier glaciations of the Alps. Passing on to the Penultimate Glaciation of the Alps (Riss), whose glacifluvial fans and terraces make up the so-called High Terrace, we find that a division into two distinct phases is widely recognized, as by Knauer in Bavaria, by Eberl in upper Swabia, by Zeuner and Kimball in the Lake Constance area, and by Beck in Switzerland. This subdivision goes back to observations made soon after Penck and Brückner published their great work in 1909. A 'Middle Terrace' and a 'Greatest Glaciation' were introduced in order to account for a supernumerary glacial phase. But as far as one can see now, the evidence justifies the statement that, between the Great Interglacial

and the Last Glaciation, two glacial phases occurred, which both correspond to the complex of the High Terrace and, therefore, are conveniently regarded as two phases of Penck's Riss Glaciation.

Prior to the Great Interglacial, Penck and Brückner distinguished two glaciations, Mindel and Günz, corresponding to the Lower and Upper Deckenschotter. It is the merit of Eberl (1930) to have studied these complexes which plainly were not simple units, and to have recognized several glacial phases in each. He found that the Lower Deckenschotter is composed of two phases of glacifluvial aggradation which both connected with moraines defined as those of the Mindel Glaciation.

The Older Deckenschotter has been subdivided into seven stages. But only the two latest of these are to be identified with Penck's Günz Glaciation which, therefore, appears to have comprised two phases.

Of the remaining five stages of the Older Deckenschotter, the three immediately preceding the Günz gravels are grouped together by Eberl as *Donau* (Danube) *Phases*; they are glacifluvial in character, and appear to be the equivalent of similar gravel sheets in northern Switzerland and southern Alsace, called *Sundgau Gravels* (Gutzwiller, 1912; van Wervecke, 1924).

The two earliest Deckenschotter stages, called *Staufenberg* and *Ottobeuren Gravels*, differ petrologically from the later ones, and their origin is uncertain, while the Staufenberg Gravels are regarded as possibly glacifluvial by Eberl, the Ottobeuren Gravels have the appearance of a Pliocene deposit, the type of weathering being different from that met with in the Pleistocene.

Correlation of the Alpine and Scandinavian successions. The correlation of the Alpine succession with the Scandinavian (north German) one is simple. The contemporaneity of Würm with Weichsel (in the widest sense) has never been questioned. In both areas we find that this Last Glaciation comprised three phases. The Riss Glaciation of the Alps (with its two phases) would then appear to be the counterpart of the Saale Glaciation of the Scandinavian sheet. This correlation is substantiated (apart from other evidence to be discussed later) by the Great Interglacial which preceded Riss, and the interglacial which preceded Saale, which must have been longer than the Last Interglacial since the underlying Elster deposits were much more deeply weathered and more widely removed by denudation than were the Saale deposits during the Last Interglacial.

Mindel of the Alps, therefore, as preceding the Great or Penultimate Interglacial, is considered the equivalent of Elster in north Germany. Again, there is evidence from the periglacial area, confirming this correlation.

All earlier glacial phases recognized in the Alps cannot yet be

identified with certainty in the area of the Scandinavian ice-sheet.[1] The Günz Glaciation (general term, *Early Glaciation*) is still to be regarded as part of the Pleistocene (Pilgrim, 1944 ; Zeuner, 1944, p. 174), but on palaeontological grounds the Donau and earlier stages are best regarded as latest Pliocene.

Thus, the glaciated areas of temperate Europe [2] reveal the succession of climatic phases summarized in fig. 39.

SCANDINAVIAN AREA	ALPINE AREA	GENERAL TERMINOLOGY		PERIOD	
POSTGLACIAL	POSTGLACIAL	PGl	POSTGLACIAL	HOLOCENE	
POMERANIAN	WÜRM 3	LGl 3	LAST GLACIATION	UPPER	PLEISTOCENE
MASURIAN INTERST.		LGl 2/3			
WEICHSEL	WÜRM 2	LGl 2			
RIXDORF INTERSTAD.		LGl 1/2			
WARTHE	WÜRM 1	LGl 1			
LAST INTERGLACIAL	LAST INTERGLACIAL	LIgl	LAST INTERGLACIAL		
SAALE	RISS 2	PGl 2	PENULTIMATE GLACIATION	MIDDLE	
		PGl 1/2			
	RISS 1	PGl 1			
PENULTIMATE INTERGLACIAL	GREAT INTERGLACIAL	PIgl	PENULTIMATE INTERGLACIAL		
ELSTER	MINDEL 2	ApGl 2	ANTE-PENULTIMATE GLACIATION	LOWER	
		ApGl 1/2			
	MINDEL 1	ApGl 1			
"FIRST" INTERGLACIAL	"FIRST" INTERGLACIAL	ApIgl	ANTEPENULTIMATE INTERGLACIAL		
	GÜNZ 2	EGl 2	EARLY GLACIATION		
		EGl 1/2			
	GÜNZ 1	EGl 1			
	DONAU STAGES AND EARLIER PHASES			PLIOCENE	

FIG. 39.—Correlation of the subdivisions of the Pleistocene established in the areas of the Scandinavian and Alpine ice-sheets. For further details, see fig. 47.

Periglacial area. Although the formerly glaciated areas of temperate Europe supply the backbone of the relative chronology, they are comparatively barren from the palaeontological and archaeological point of view. Most of the famous sites which have yielded

[1] There is faunal evidence for two cold phases corresponding to Alpine Günz, in the East Anglian Crags. See Zeuner (1937*a*). Pre-Elster boulder-clays have been found by van Wervecke.

[2] The British succession is of a similar type as that of north Germany, with which it can be correlated. For details, see Zeuner (1937*a* ; 1944, Chapter IV).

abundant faunal remains and artefacts of man are situated in a zone which, during the glacial phases, was not itself glaciated but suffered an intense frost climate. This *periglacial zone* may be defined as the zone in which during any particular glacial phase the climate favoured permanently frozen subsoil (*tjaele*) as is found at the present day in northern regions from Lappland to Siberia and central Asia, and in Alaska (Leffingwell, 1915). Much work has been done on this phenomenon in recent years, especially by Russian workers. Its occurrence in the Pleistocene of central and west Europe has been abundantly confirmed (pl. XI, figs. A, B, and pl. XII, fig. A).

Solifluction. Closely connected with the phenomenon of tjaele is that of *solifluction.* Since water, especially the meltwater of snow in spring, is prevented from seeping away by the frozen subsoil, the thawed upper stratum of the soil becomes so water-logged that it is liable to move down any inclined surface. Since heavy frost produces, by repeated freezing and thawing, vast quantities of fresh debris, the material which is transported to the valley bottoms is rapidly replaced, and the process continues so long as the frost climate persists. Solifluction deposits, therefore, are a conspicuous feature of sections from the periglacial zone (pl. XII, fig. C).

Tundra. The periglacial zone comprises three chief types of environment, tundra, loess steppe, and taiga. The tundra is the sub-zone of dwarf shrubs and mosses, and of abundant peat formation. It is now restricted to the polar zone. Fossil evidence shows that it was closely associated with the sandrs and generally dominant near the ice-margin. In central Europe its belt was about 50 miles wide during the more intense glacial phases, though it certainly reappeared in more distant patches, particularly in the hills. The tundra sub-zone must not be visualized as an unbroken cover of vegetation; most of the ground was probably barren, and plant growth confined to valley sides and other favourable localities, as it is now to be observed in Spitsbergen or Greenland.

Loess steppe. The loess steppe constituted the middle belt of the periglacial zone. It was distinguished from the tundra by its drier soil and climate, deposition of dust brought by the winds from the bare surfaces of moraines, gravel-spreads and mountains being its characteristic feature. The vegetation was probably of the short-grass steppe variety. The loess steppe required a continental climate. It did not develop on any large scale in central and west Europe during the weaker glacial phases (third phase of Last Glaciation, for instance), though during the more intense ones it extended its area to the coast of Normandy (fig. 40). The loess belt increased in width eastwards, attaining to several hundred kilometres in south Russia.

The periglacial loess steppe, the climate of which has been reconstructed in some detail (Zeuner, 1937*b*), provided ample food, at

least during certain seasons, for grazing mammals. It was, therefore, of great economic importance for early man, and many hunting sites have been discovered in loess deposits.

From the point of view of prehistoric chronology, the European loess belt is the most important of all Pleistocene formations. Since vast quantities of loess were deposited in places removed from the destructive activity of running water, the chances for the preservation of sections were comparatively good. On the loess formed during a glacial phase, an easily recognizable weathering soil developed in

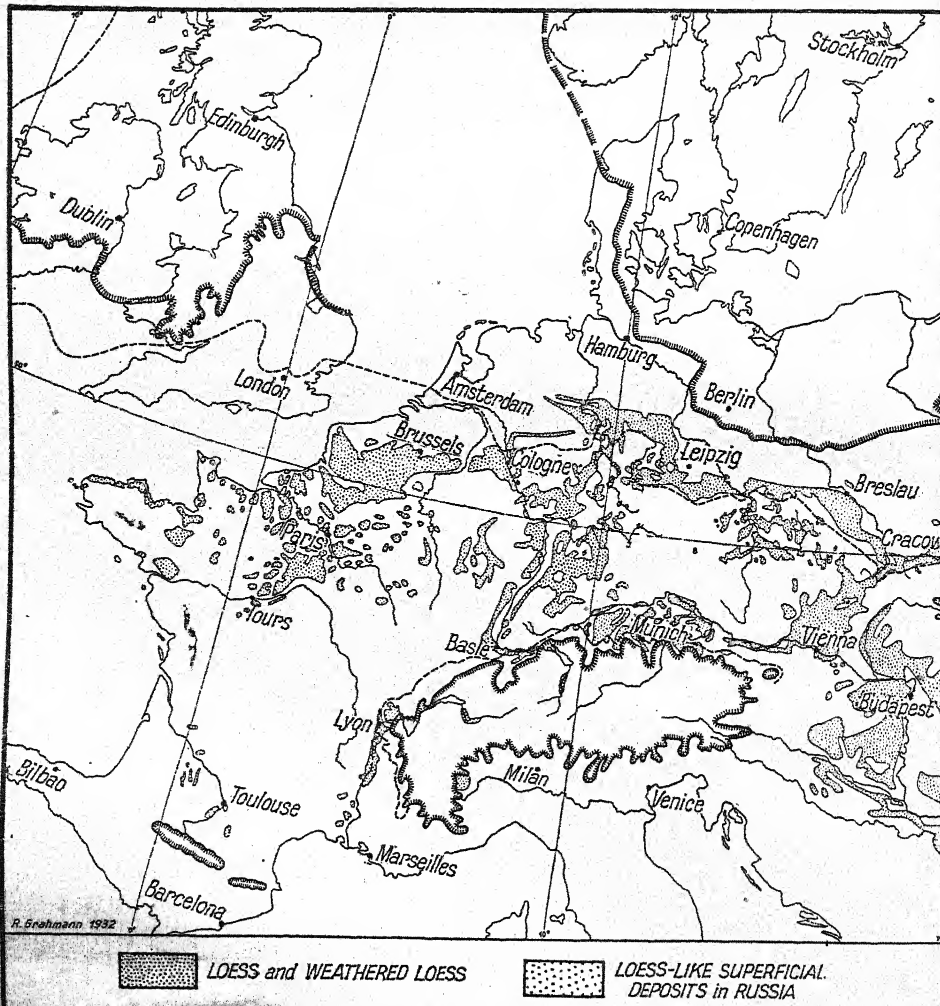
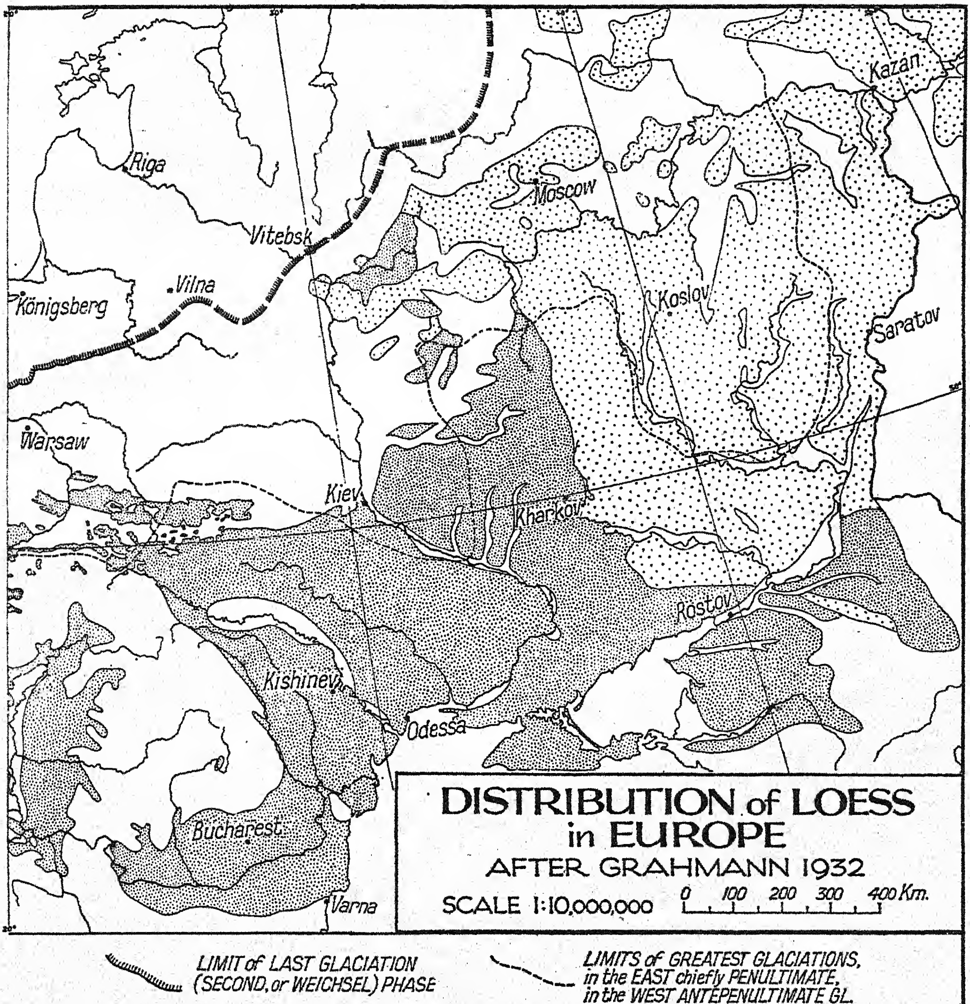


FIG. 40.—The loess belt of Europe. Some loess is present in southern England

the milder climate of the following interstadial or interglacial (pl. XII, fig. B). This soil, in turn, was buried under fresh loess brought during a later glacial phase. The succession of fresh loesses and soil horizons, therefore, provides us with a most valuable climatic record, from which a minimum number of alternating cold and temperate phases has been derived. Many instances will be described in Chapter VI. Here it suffices to say that in central and west Europe, up to 6 loesses can be distinguished, whilst the number is larger in eastern Europe. As many as 11 have been recorded from Hungary.



but has not yet been mapped. After Grahmann, Mitt. Ges. Erdk. Leipzig, 1932.

The following summary of loess phases is based on northern France and west Germany:

Postglacial and modern surface soil	Three Phases of Last Glaciation
Younger Loess III ? (very restricted)	
Very thin soil	
Younger Loess II	
Soil	
Younger Loess I	
Thick soil indicating a long period of intense weathering, climate at times warmer than now. 'Argile rouge' of northern France.	Last Interglacial
Upper Older Loess	Earlier Glacial Phases
Soil	
Middle Older Loess	
Soil	
Lower Older Loess	

The correlation of this succession with that of the glacial phases is rendered possible by the climatic terraces of the rivers, on which loess was deposited and which were covered by glacial deposits (moraine and varved clay) in districts reached by the ice. In order to appreciate this evidence it is necessary to consider sections in detail. A few instances are given in Chapter VI.

Taiga. To the south and south-west, the periglacial zone was bordered by temperate forest which extended far into the present Mediterranean region (Chapter VII). Yet, the transition from the loess steppe with its dry-continental climate and, as a rule, permanently frozen subsoil to the forest with its more humid climate and not-frozen soil cannot have been abrupt. It is to be assumed that a transitional zone of stunted coniferous forest on frozen subsoil intervened between the two, similar to the *taiga* of northern Europe and Siberia. There is no direct evidence for taiga in the periglacial zone, but near the southern margin of the loess belt, strips of country which might have been favourable for the development of forests even during a cold phase (slopes of river valleys, for instance) are in fact devoid of loess. This peculiar absence of loess from districts where one would expect to find it, can be explained by the assumption of forest growth. Stunted forest of the taiga type may have played a larger part in periglacial Europe than is commonly assumed. There are several species of mammals in periglacial faunas which are now typical of the taiga, such as the glutton.

Soils, and weathering in a temperate climate. Moraines, loess and solifluction are evidence of a cold climate. We have repeatedly had occasion to mention that mild climates are often indicated in the

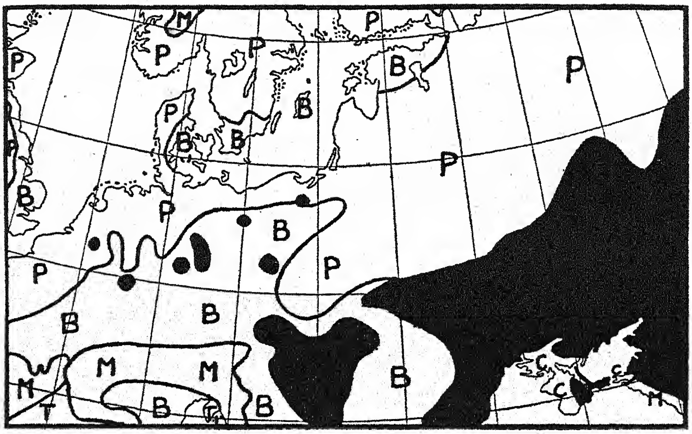


FIG. 41.—Soil chart of Europe, much simplified. Black: chernozem; B: Brownearth; P: podsol; M: mountain soils; T: Terra Rossa, a Mediterranean soil; C: chestnut soils, dry-continental to semi-desert soils. Note the islands of chernozem in central Europe, which correspond to relatively dry and warm localities.—From Zeuner, 1944.

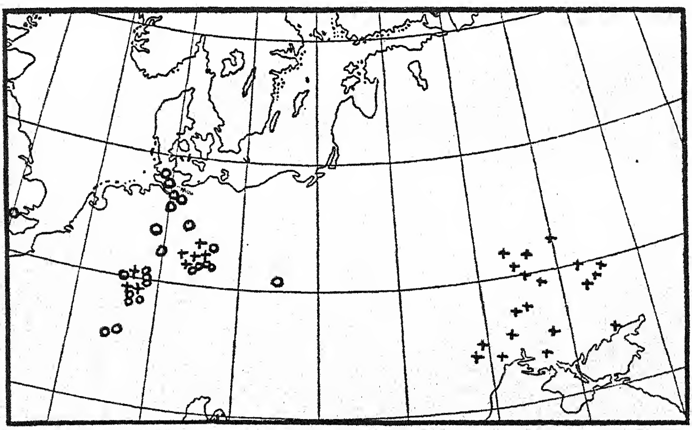


FIG. 42.—Soils of the Last Interglacial. Cross: chernozem. Circle: brownearth or podsol. Note the similarity in distribution of these fossil soils with those of the present day (fig. 41). It indicates that the climate of the Last Interglacial was, for some considerable time, similar to that of the present day.—From Zeuner, 1944.

sections by *buried soils*, i.e., horizons formed by chemical weathering from land-surfaces which are now covered by later deposits. The process of chemical alteration of the surface down to a depth of

(usually) a few feet is almost completely impeded in frost climates. In temperate climates, certain characteristic kinds of soil are formed, such as podsol, brownearth and chernozem. The last-mentioned, a blackish soil, is developed in steppes with a hot summer and cold winter. Brownearth and podsol soils are characteristic of the humid-temperate countries.

In a section, the presence of a weathering soil is sufficient to indicate a temperate climate, but though most soils are conspicuous to the eye (pl. XII, fig. B) it is always necessary to confirm their presence by chemical or mechanical tests. When a large amount of data has been collected from localities exhibiting soils of a certain interglacial, it is possible to construct charts for the distribution of types of soils during that period. This has been done for the Last Interglacial, as shown in figs. 41 and 42.

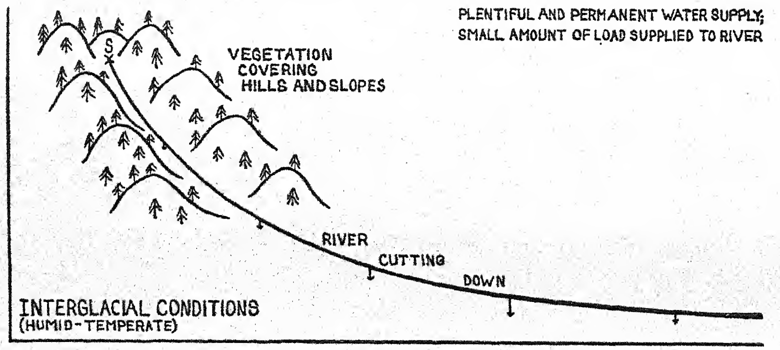


FIG. 43.—A river cutting its valley under ordinary, humid-temperate, conditions.—From Zeuner, 1944.

Periglacial river terraces. The most important evidence for the sequence of climatic phases in the periglacial zone is provided by the rivers of central Europe. Being far removed from the sea, these rivers were not influenced by the fluctuations of the sea-level; being situated in that narrow portion of the periglacial zone which separated the Scandinavian and Alpine ice-sheets, they responded readily even to minor changes of climate. During temperate phases (as to-day), these rivers contained sufficient water to carry some load and to erode at the same time (fig. 43). Down-cutting of the river's bed, therefore, took place mainly while the climate was temperate. On the other hand, while the climate was of the periglacial type (fig. 44), solifluction brought enormous quantities of rock-waste into the river, the springs supplied little water during most seasons, and the over-loaded rivers deposited their surplus load (pl. XIII, figs. A, B). During the next temperate phase, erosion was resumed, the gravel aggradation was quickly cut through and erosion usually cut into

the underlying bed-rock until the climate became periglacial again. Thus, an *aggradation terrace* was formed.[1] The repetition of the process resulted in a sequence of river terraces, each indicating a phase of periglacial climate, and the erosional steps representing interstadials or interglacials.

The investigation of the climatic terraces of European rivers was greatly advanced by Soergel (1921). It has since been elaborated still further by many workers. Their results have supplied evidence for a succession of climatic phases which agrees well with the succession of phases found in the glaciated areas, particularly in the Alps.

Now, a correlation of the sequence of terraces with the sequence of glaciations can be effected in certain areas where the Elster and Saale glaciers advanced far up the valleys of the rivers under consideration. Their moraines and varved clays were deposited, con-

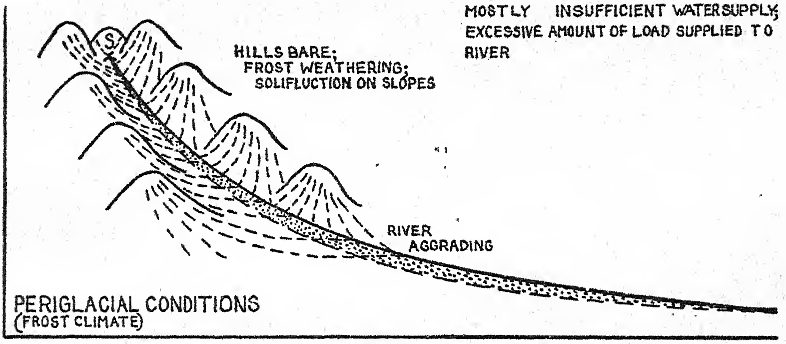


FIG. 44.—A river aggrading a gravel-sheet under the influence of the periglacial climate.—From Zeuner, 1944.

formably, on the gravel aggradation formed by the river while the ice was advancing. This conformable superposition of glacial sediments on river gravel provides a valuable stratigraphical criterion. The correlation of river terraces and glacial phases effected in this manner is best given in the form of a table (fig. 45).

General terminology of climatic phases. This work on climatic river terraces has confirmed the detailed chronology based on the glacial phases of the Alps to such an extent that one is justified in abstracting from it a sequence of climatic phases applicable to temperate Europe in general. It is not advisable, therefore, to extend the use of a local terminology, such as the Alpine one, to other areas, but rather to adopt a neutral terminology of climatic phases which can be used when no reference is made to a local succession.

[1] Actually the aggradation took place while the climate was deteriorating, and the erosion began when the climate began to improve after the climax of the glacial phase. This detail need not concern us here. See Zeuner, 1944, p. 25.

In this way, the local terminologies, especially the much misused Alpine one, retain their original, geographically restricted, significance. If, therefore, Saale or Weichsel is mentioned in this book, a glacial phase of the Scandinavian ice-sheet is being discussed. If terms like Riss or Würm are used, phases of the Alpine ice-sheet are referred to. But if the *general terminology* (fig. 39, column 3), for instance Antepenultimate Glaciation, or an abbreviation like $LGl_{2/3}$, is used, the climatic phase as such is meant irrespective of local conditions. The distinction here made may appear unnecessarily dogmatic, but

SILESIA	MULDE-ELSTER	ILM-SAALE	WERRA-WESER	RHINE	CONFORMABLY COVERED BY
	pl s φ ?	PREGLACIAL T. IV	VII	a very high terrace	
	pl s φ ?	PREGLACIAL T. III	VIII	a very high terrace	
	II (p2 s φ)	PREGLACIAL T. II	IX	? upper part of MAIN TERRACE	
f(?g)	TERR. I	PREGLACIAL T. I	X	MAIN T.	ELSTER MORAINE
(e)	–	GLACIAL T. 1	I1a	–	
d	TERR. 1	GLACIAL T. 2	I1b	HIGH TERRACE or UPPER MIDDLE T.	
c	TERR. 2	GLACIAL T. 3	MAIN T.: I1c	LOWER MIDDLE T.	SAALE MORAINE
–	–	GLACIAL T. 4	I2	–	
b	d3	GLACIAL T. 5	Pa	LOW T.	YOUNGER LOESS I
a	da	GLACIAL T. 6	Pb	INSELTERRACE (LOWER LOW T.)	YOUNGER LOESS II
FLOOD-PLAIN	FLOOD-PLAIN	FLOODPLAIN (GLAC. T. 7?)	Pc	?	

FIG. 45.—Correlation of river terraces in central Europe. Silesia, Oder system. Mulde, Elster, Ilm, Saale, tributaries of the Elbe. Werra-Weser, system of the Weser. Rhine, terraces in, and north of, the Rhenish Schiefergebirge.—After Zeuner (1938).

the confusion brought about by the indiscriminate use of the Alpine terms in all parts of the world, and the need to distinguish local succession and climatic fluctuations for the purposes of the absolute chronology, has, after much hesitation, convinced me that it is better to introduce a simple general terminology which both in its full and in its abbreviated form is readily intelligible.

Minor phases. The table, fig. 45, which summarizes the systems of river terraces, further illustrates a point which, though unimportant in the present context, will re-appear from time to time in our regional survey and which assumes significance in the establishment of the

absolute chronology. It is the existence of 'supernumerary' cold phases which are represented by aggradation terraces but of which no equivalent glacial phase is known with certainty. These terraces do not occur everywhere, and their contained faunas do not indicate a thoroughly cold climate. They have been regarded, therefore, as evidence for minor cold phases which were not sufficiently intense to produce large ice-sheets. There is at least one such phase in the Last Interglacial, and one or two in the Penultimate Interglacial.

These terraces are not the only suggestion of minor cold phases. In several interglacial deposits, strata have been found intercalated which suggest that the climate was for a while cool or even subarctic. The best example is the Danish Middle Bed in Jutland, which divides the series of the Last Interglacial into two warm subphases and whose cold character is proved by its floral content. Another locality of this type is Hoxne in East Anglia. Here, however, it is as yet impossible to determine on geological evidence whether the deposits date from the Last or the Penultimate Interglacial.

Eustatic fluctuations of the sea-level. In countries bordering the sea, the rhythm of erosion and aggradation of the rivers is of a different nature. Although the climatic factors have operated here also, they were far outweighed by the adjustments of the rivers to the oscillations of the sea-level. Let us therefore briefly consider first the movements of the sea-level in the course of the Pleistocene.

Changes in the height of the sea-level have been referred to on many occasions in the preceding chapters. The isostatic changes connected with the rising of Fennoscandia during late Glacial and Postglacial times were described in some detail in Chapter III (p. 47), but outside the isostatically affected areas [1] evidence has accumulated for phases during which the sea-level was higher or lower than at present over large portions of the earth's surface. These ancient sea-levels are held to be of the eustatic type.[2] Many of them are of Pleistocene age and contemporary with certain phases of the Palaeolithic. Although the study of the Pleistocene sea-levels is still in its initial stage, it promises to become important for the correlation of climatic phases and prehistoric industries over very great distances, and I am confident that the 'raised beaches' will eventually provide a link in dating Pleistocene and Palaeolithic in coastal regions all over the world.

Pleistocene high sea-levels. Systematic work on Pleistocene sea-levels was begun by Depéret (1906) and de Lamothe (1911) in the Mediterranean, the former working on the Italo-French Riviera, the latter in Algeria. The work was subsequently extended to the Atlantic coasts of Europe and to other continents, and the high

[1] I.e., in England, approximately south of 52° N. lat.

[2] See plates XIV, figs. A, B; XV, figs. A, B; XVII, fig. A; XXI, figs. A, B.

measure of agreement obtained has led to the elaboration of the *theory of glacial eustasy* or of *glacial control* of the sea-level (for instance, Daly, 1934) which assumes that phases of high sea-level evidenced by what are often loosely called *raised beaches* [1] correspond to interglacials, and phases of low sea-level to glaciations.

The determination of the exact mean sea-level of the time when an ancient shore-line was formed is of primary importance though it has been sadly neglected by many authors. The figures given are often no more than estimates. In spite of this difficulty, the sequences of high sea-level phases observed in different regions of the world are in good agreement with one another, as is shown in the following table (fig. 46).

Heights in Metres	Average	Algiers	South France	Jersey	North France	South England	South Africa	Sunda Archip.	South Austral.	North America
Sicilian	100 m.	103	90–100		103	*c.* 96			(75)	81
Milazzian	60 m.	*c.* 60	55–60		56–59	*c.* 60	45–75		60 (45)	65 49
Tyrrhenian	32 m.	*c.* 30	28–32	32–34	32–33	(36·5) 33·5			27	29
Main Monastirian	18 m.	18–20	18–20	18	18–19	15–18	18		19·5	20
Late Monastirian	7·5 m.		7–8	7·5	8	5–8	6		7·5	8
pre-Flandrian regression			min. −92		min. −30			−70 to −100		

FIG. 46.—The succession of shore-lines in various regions of the world, and the nomenclature of the high sea-levels.—After Zeuner, 1942.

It is most convenient to apply to these sea-levels the nomenclature of Depéret, and to define them by their average height above the present sea-level. If one does so, the only modification required of Depéret's well-known classification is the subdivision of the Monastirian into a Main phase and a Late phase. In addition, Dubois's term, Flandrian, for the rise of the sea from the low level of the Last Glaciation to the comparatively high level of the present day, may be used. The question of the terms to be applied to these ancient sea-levels has been complicated in recent years by palaeontological and archaeological considerations. In order to avoid increasing confusion, I am inclined to continue following Depéret, and Dubois (1936), who also advocates the retention of Depéret's system. It is important to remember, however, that the term Sicilian is

[1] Strictly, this term might be thought to imply tectonic uplift of the beach. Since areas of tectonic disturbance have to be eliminated in the process of reconstructing ancient eustatic sea-levels, it is advisable to discontinue the indiscriminate use of 'raised beach', and to replace it by *ancient beach, ancient shore-line*, or some other non-committal term.

often used to include the Milazzian, and the term Tyrrhenian, the Monastirian.

High sea-levels and interglacials. If one accepts the theory of glacial eustasy, that the low sea-levels were caused by the locking-up of water in the ice-sheets of the glacial phases, and the high sea-levels by the return of the water to the oceans, the question arises as to which phase of high sea-level corresponds to which interglacial.

In northern France and the Channel Islands, the two Monastirian beaches are covered by Younger Loess; they are, therefore, older than the Last Glaciation. Moreover, they are followed by the pre-Flandrian regression to a very low level, which was contemporary with the Last Glaciation, as shown by Dubois in Flanders and by Blanc in Italy. This renders a Last Interglacial Age of the Monastirian sea-level highly probable. Its subdivision into Main and Late Monastirian has never been taken as evidence for two different interglacials, it is readily explained by the minor cool phase which occurred during the Last Interglacial (Glacial Terrace IV of Thuringia, fig. 45; Danish Middle Bed, Zeuner, 1944, p. 126).

Postponing the Tyrrhenian for the moment, we find that there is good and consistent evidence for the Milazzian sea-level being that of the Antepenultimate Interglacial. It is supplied, for instance, by the *Machairodus*-fauna of the corresponding terrace of the Somme at Abbeville, and by Wooldridge's observation that the Milazzian level of the London Basin is later than the Norwich Crag which, again on palaeontological evidence, is approximately contemporary with the Early Glaciation.

If the Milazzian sea-level is to be correlated with the Antepenultimate Interglacial, and the Monastirian with the Last Interglacial, the Tyrrhenian sea-level must be that of the Penultimate or Great Interglacial. This correlation has stood the test of application in numerous instances.

Low sea-levels and glaciations. Evidence for low sea-levels intercalated between two phases of high sea-level and corresponding to glacial phases is naturally scanty. Apart from the low level of the Last Glaciation (pre-Flandrian regression, probably attaining to almost − 100 metres), which is comparatively well-known from beach deposits below present sea-level and from submarine platforms, low levels can be deduced from the presence of buried channels in the lower courses of many rivers. These will be discussed presently, but it may be noted that it has not been possible to deduce from them more than minimum values for the drop in sea-level. Boule, however, has suggested that one of the earlier low levels was as low as − 200 metres. One is inclined to correlate this extreme recession with one of the large glaciations, like the Penultimate or Antepenultimate Glaciation.

Thalassostatic river terraces. Returning now to the terraces of

the rivers, it has been said before (p. 127) that in the lower course near the sea, the fluctuations of the sea-level prevail over the climatic rhythm. Hence, river terraces formed under the influence of the changing sea-level may be called *thalassostatic terraces*. Since the sea-level was high in the interglacials (and relatively high, it may be assumed, in the interstadials), we find that the mild phases are characterized by compensatory aggradation, the river building up its bed as the sea-level gradually rises. The gravel sheets deposited in this manner, therefore, contain predominantly warm faunas; and the surface of the aggradation runs into the mean high-tide level of the interglacial in question. This fact permits us to calculate the heights of interglacial sea-levels with fair accuracy.

On the other hand, when, during a glacial phase, the sea-level was low, the gradient of the lower course of the river was much increased, and the resulting erosion cut a narrow valley, and sometimes a gorge, graded to the low sea-level of that time. Since the climate was cold, solifluction was active and we indeed find the slopes of such channels lined with solifluction strata.[1]

When the sea rose again after the termination of the glacial phase, the channel at first became a funnel-shaped estuary, but, time permitting, this was filled with deposits of an interglacial character. These channels, some of which reach much below the present river-level, are called *buried*, or *sunk*, *channels*. They are typical of the Thames, Somme, Tiber and many other rivers.

In its course near the sea, therefore, a river aggrades during the mild phases and erodes during the cool phases. This thalassostatic rhythm is the converse of the climatic rhythm which prevails in the upper course. The thalassostatic terrace system extends only slightly beyond the highest point reached by the tides; it is here that it meets the climatic system of inland terraces. Since the transition from one system to the other depends on the intensity of the glacial phase, the amount of drop of the sea-level and several other factors, the stretch of the river's course where climatic aggradations dip into thalassostatic erosion channels, and where interglacial down-cutting is replaced by estuarine aggradation, varies from one glaciation to the next. It is natural, therefore, that in the zone of transition, stratigraphical conditions are so complex that they are extremely difficult to disentangle. In the Thames, this zone lies just upstream from London.

Terraces of the Thames. Downstream from London, the Thames shows the reactions of a river to the changes of the sea-level so clearly that it may be summarized as an example:[2]

[1] These are sometimes represented as lining the entire channel. They cannot have done so since, where the river was flowing, it would have swept them away or resorted them.

[2] For details and references, see Zeuner, 1944, p. 114 ff.

River stage	Height of sea-level	Sea-level phase	Climatic phase
Ambersham Terrace	200 ft. (60 m.)	Milazzian	ApIgl
Downcutting Thames Valley glaciation	Relatively low		ApGl
Followed by further erosion and aggradation in stages, until the aggradation of the High Terrace (Swanscombe)	107 ft. (32 m.)	Tyrrhenian	PIgl
Cutting of Taplow Bench, followed by solifluction and loess	Below O.D.		PGl
Taplow Terrace aggradation	60 ft. (18 m.)	Main Monastirian	LIgl
Cutting of Upper Floodplain Bench			
Upper Floodplain aggradation	25 ft. (7·5 m.)	Late Monastirian	
First Buried Channel	Much below O.D.		LGl_1
Lower Floodplain Terrace	Few feet above O.D.		$LGl_{1/2}$
Second Buried Channel	Below O.D.		LGl_2
Filling of Second Buried Channel	[illegible] but remaining below O.D.		$LGl_{2/3}$
Third Buried Channel	Below O.D.		LGl_3
Tilbury Filling Stage	Up to present sea-level	Flandrian	PGl

Fauna and fluctuations of climate. A few words remain to be said about the use of palaeontology in Pleistocene stratigraphy, since the fauna will be referred to frequently in later chapters.

The land faunas [1] consist chiefly of mammals and mollusca, the former being the more conspicuous and, climatically, more easily interpreted.

Owing to the short duration of the Pleistocene compared with other geological periods, there are no species which characterize exclusively one of the climatic phases. There are a few species and genera, however, which disappear at the end of the Lower Pleistocene, such as *Elephas meridionalis*, *Dicerorhinus etruscus* (a rhinoceros), *Equus stenonis* (group of horses allied to zebras), *Trogontherium cuvieri* (a large beaver). They are of great stratigraphical value.

At the beginning of the Upper Pleistocene, many species which had hitherto been rare, become very frequent, and they are useful in

[1] See Zeuner, 1944, Chapter X.

stratigraphical work, though not as individual finds, but as members of fossil assemblages. There are, for instance, the mammoth (*Elephas primigenius*), the woolly rhinoceros (*Tichorhinus antiquitatis*), the reindeer (*Rangifer tarandus*), the cave bear (*Ursus spelaeus*), the arctic fox (*Alopex lagopus*), &c. Their frequent occurrence in a deposit usually indicates one of the three phases of the Last Glaciation.

Land faunas further provide valuable environmental evidence, at any rate in the Upper Pleistocene. A beaver, for instance, which is dependent on wood for the building of its burrows and dams, suggests forests. Forests are further suggested by faunas comprising the straight-tusked elephant (*Elephas antiquus*), red deer, elk, brown bear (*Ursus arctos*), lynx. Arctic fox and variable hare, if frequent, and associated with reindeer and other subarctic forms, indicate tundra or taiga. Horses, asses, antelopes (Saiga antelope), jerboas, &c., may safely be taken as evidence of steppe conditions; these species are typical of the loess.

The study of the fauna, therefore, helps a great deal in the reconstruction of the environment of early man; but unless done with care, it lends itself to incorrect conclusions. The presence of odd specimens of a species should never be taken too seriously, as they may be derived from older deposits, or if contemporary with the fauna studied, they may be stragglers from another biotope. Instead, the fauna should be analysed and assessed as a whole. It may also not be superfluous to warn against uncritical acceptance of the faunal lists of some authors. Many a time a limb bone of an elephant has been listed as 'mammoth', and ribs or vertebrae of a rhinoceros as 'woolly rhinoceros', merely because it did not occur to the author that it could be another species. Since both species mentioned are characteristic of periglacial environments, the implications of such misidentifications—which often can no longer be checked—are obvious.

Summary. The stratigraphical evidence outlined in the preceding paragraphs may now be summarized in the form of a comprehensive table (fig. 47). The climatic divisions established are no more than the result of a gradual refinement of the special methods which have to be applied in the stratigraphy of the Pleistocene. The earliest conception of the Pleistocene was that of one great Ice Age. Then interglacial deposits were discovered, and two glaciations were generally assumed. The next step was the discovery that there was more than one interglacial. Among the several ensuing stratigraphical systems, Penck and Brückner's was the most noteworthy, since it retained the original 'only' interglacial in the form of the Great Interglacial and subdivided the two original glaciations into two each. Now, the detailed relative chronology of the Pleistocene, which embodies the stratigraphical work of the 30 odd years that have elapsed since Penck and Brückner

SCANDINAVIAN ICE-SHEET	ALPINE ICE-SHEET	LOESS	PERIGLACIAL RIVERS	THALASSOSTATIC RIVERS	SEA-LEVEL	GENERAL TERMINOLOGY		
POSTGLACIAL	POSTGLACIAL	WEATHERING		AGGRADATION UP TO PRESENT SEA-LEVEL	FLANDRIAN TRANSGRESSION	PGl	POSTGLACIAL	
FENNOSCANDIAN M.	?HALT IN MOUNTAINS							
POMERANIAN	WÜRM 3	?YOUNGER LOESS III	FLOODPLAIN OR T. 7	3RD BURIED CHANNEL	? c. −30 m. (GENERALLY LOW)	LGl 3	LAST GLACIATION	PLEISTOCENE: UPPER
		WEATHERING			?ABOVE −12 m.	LGl 2/3		
BRANDENB.=WEICHSEL	WÜRM 2	YOUNGER LOESS II	TERRACE 6	2ND BURIED CHANNEL	? c. −70 m.	LGl 2		
		WEATHERING		SLIGHTLY ABOVE FLOODPL.	c. +1-3 m.	LGl 1/2		
WARTHE	WÜRM 1	YOUNGER LOESS I	TERRACE 5	1ST BURIED CHANNEL	c. −100 m.	LGl 1		
LAST INTERGL.: DANISH MIDDLE BED	LAST INTERGLACIAL	DEEP WEATHERING: "ARGILE ROUGE"	TERR. 4	"25 FT." TERRACE; "50 FT." TERRACE	LATE MONASTIR., 7·5 m.; INTRA-MONASTIRIAN; MAIN MONASTIR., 18 m.	LIgl	LAST INTERGLACIAL	
SAALE	RISS 2	UPPER OLDER LOESS	TERRACE 3	EROSION	VERY LOW	PGl 2	PENULTIMATE GLACIATION	PLEISTOCENE: MIDDLE
		WEATHERING				PGl 1/2		
	RISS 1	MIDDLE OLDER LOESS	TERRACE 2			PGl 1		
GREAT INTERGLACIAL	GREAT INTERGL.: ?GLÜTSCH; ?KANDER	DEEP WEATHERING AND MUCH DENUDATION	?TERR. 1	"100 FT." TERRACE; VARIOUS BURIED AGGRADATIONS	TYRRHENIAN, 32 m.	PIgl	PENULTIMATE INTERGLACIAL	
ELSTER	MINDEL 2	LOWER OLDER LOESS	TERRACE I	EROSION	VERY LOW	ApGl 2	ANTE-PENULTIMATE GLACIATION	PLEISTOCENE: LOWER
?EARLIER PHASES						ApGl 1/2		
	MINDEL 1		TERRACE II			ApGl 1		
	"FIRST" INTERGLACIAL			"200 FT." PLATFORM	MILAZZIAN, 60 m.	ApIgl	ANTE-PENULTIMATE INTERGLAC.	
	GÜNZ 2		TERRACE III		LOWER	EGl 2	EARLY GLACIATION	
						EGl 1/2		
	GÜNZ 1		TERRACE IV			EGl 1		
	DONAU 3		EARLIER PREGLACIAL TERRACES	EARLIER HIGH LEVELS AND TERRACES	SICILIAN, 103-80 m.		UPPER PLIOCENE	
	DONAU 2							
	DONAU. I							
	STAUFENBERG							
	OTTOBEUREN							

FIG. 47.—General correlation of the subdivisions of the Pleistocene of Europe. Based chiefly on north Germany for Scandinavian ice-sheet, upper Swabia and Lake Thun (Eberl and Beck) for Alpine ice-sheet, Rhine Valley (Mainz Basin and Mauer) for Loess, Thuringia for Periglacial Rivers, Thames and Somme for Thalassostatic Rivers, Mediterranean and Channel coasts for Sea-levels.

published their scheme, shows that each of Penck's glaciations can be subdivided still further. The long duration of the Great Interglacial has been confirmed, and several minor cool phases appear to have interrupted the interglacials.

In order to appreciate the strength of the argument for the astronomical theory of the fluctuations of Pleistocene climate, and for the absolute chronology, it is necessary to remember that the curiously irregular rhythm of the cold phases, namely: two, short interglacial, two, long interglacial, two, short interglacial, three, has not been read into the evidence, but is the outcome of stratigraphical research in particularly favourable parts of temperate Europe.

B. THE ASTRONOMICAL THEORY

The problem of the duration of the Ice Age, counted in years, has fascinated workers since the early days of Pleistocene geology. Two ways were open to attack it, and both have been used many times, namely (*a*) the estimation of the duration based on the rate of sedimentation, and (*b*) the development of an astronomical time-scale from the periodical perturbations of the earth's orbit. The second method is the more ambitious since it promises more accurate figures both for the whole Pleistocene and for its subdivisions. The greater part of the present section will be devoted to it, but since methods (*a*) and (*b*) are independent of each other, they provide an important mutual check. For this reason, some results of the first method are summarized in the following paragraphs.

Rate of sedimentation used to estimate duration of Pleistocene. The most notable application of the rate of sedimentation is by Penck and Brückner. They relied on estimates for the length of the time elapsed since the ice withdrew from certain lakes on the northern edge of the Alps in Switzerland. Heim found 16,000 years for a delta built into Lake Lucerne, Steck 20,000 years for the delta between Lakes Thun and Brienz at Interlaken, and the same author for the Aare delta in Lake Brienz 14,000 to 15,000 years. From these figures Penck and Brückner deduced the age of the Magdalenian station of the Schweizersbild near Schaffhausen (see p. 154) as 24,000 years. This site was occupied during Würm 3, as is known from geological evidence.

Having obtained this estimate, Penck proceeded to compare the depth of erosion since Würm 3 with the amounts of down-cutting which occurred during his three interglacials. In a corresponding manner, the depth of weathering was used also. Thus he found that the Last and the 'First' Interglacial lasted for about 60,000 years each, and that the Great Interglacial was about four times as long, namely 240,000 years. These estimates were expressed in the form of a curve, in which the total duration of the Pleistocene is given as 600,000 years. Considering the very slender basis on which

this estimate relies, its results are astonishingly good, as will be seen from a comparison with the astronomical figures to be given later.

Other estimates for the duration of the Pleistocene suffer from the ambiguity of the lower limit of the period. Reasons have been given elsewhere (Zeuner, 1944, p. 174) for fixing the *Plio-Pleistocene boundary* just before the Early Glaciation. But there are few areas where definite evidence for the Early Glaciation is available, and judging by the presence of pre-Günzian phases in the Alps and of corresponding river terraces in the periglacial area, we must assume that climatic conditions resembling those of the Pleistocene obtained in the final Pliocene. Estimates for the duration of the Pleistocene which cannot use the Early Glaciation as a starting-point, therefore, are likely to yield figures higher than 600,000 years.

A particularly interesting estimate for the Pleistocene of an unglaciated area was made by Rutten in Java. He used the rate of sedimentation and obtained one million years.

Finally, it may be mentioned that estimates based on the disintegration of radioactive minerals (see Chapter X) assign one or two million years to the Pleistocene. Unfortunately, they come from volcanic rock of very uncertain, Pliocene or Pleistocene Age. Nevertheless, taking into account this uncertainty, the figures calculated on this basis (one or two million years) are of the same order as those derived from the rate of sedimentation.

The astronomical method. The astronomical chronology of the Pleistocene is not based on geological considerations, but on a theory which explains the fluctuations of the climate. This theory makes the periodical *perturbations*, which the orbit of the earth suffers owing to the mutual attraction of the planets, responsible for changes in the amount of radiation received by the earth from the sun. Among these perturbations, there are three of especial interest in this connexion, (1) the obliquity of the ecliptic, (2) the eccentricity of the orbit, and (3) the precession of the equinoxes. Very little space can here be allowed for an explanation of these phenomena.

Perturbations. The *obliquity of the ecliptic* is the angle between the equatorial plane of the earth and the plane of the orbit. It is at present 23° 27′, and it is known to have varied between 21° 39′ and 24° 36′. The obliquity produces the seasons, and it is one of the factors modifying the climatic zones. A decrease of the obliquity diminishes the seasonal differences but increases the distinction of the climatic zones, whilst an increase of obliquity intensifies the seasonal differences and reduces the differences between the climatic zones. The obliquity fluctuates with a period of approximately 40,000 years.

The *eccentricity of the orbit* is our second variable. Since the sun does not occupy the centre, but one of the focuses of the ellipse of the orbit, there is a time of the year when the earth is nearer

to the sun than during the remainder of the year. The point of the orbit which is nearest to the sun is called the *perihelion* ; at present, the earth passes through it in the winter of the northern hemisphere. It is obvious that more radiation is received by the hemisphere which passes the perihelion in summer (i.e. at present the southern hemisphere), but this effect is counteracted by the shortening of the portion of the orbit which contains the perihelion. This is easy to see if one draws an ellipse, with the sun in one focus, the axis major joining the point nearest to the sun (perihelion) with the point farthest away from the sun (*aphelion*). The spring and autumn equinoxes are then given where the line laid through the sun at right angles to the axis major meets the ellipse representing the orbit. The line connecting the equinoxes divides the ellipse into two unequal portions, that containing the perihelion being the shorter. The winter of the northern hemisphere is at present $7\frac{1}{2}$ days shorter than the summer.

The smaller the eccentricity, therefore, the smaller will be the differences in the lengths of the seasons. The eccentricity fluctuates with periods of 92,000 years.

The third perturbation of importance is a slight conical movement of the earth's axis. It results in a slow shifting of the *cardinal points* (spring equinox, summer solstice, autumn equinox, winter solstice), which delimit the seasons. Because of this movement it is called the *precession of the equinoxes.* It has received much attention in the past.

Its period, as seen from the earth, is about 26,000 years. But owing to the attraction by other planets, the elliptic orbit as a whole swings round in the sense opposite to the direction of the precession. Thus, if one takes for instance the perihelion as zero point on the orbit, a complete circuit of any one cardinal point requires *less* time, namely 21,000 years. Within the latter period the radiation received from the sun fluctuates in a certain manner. The most convenient way of defining the position of the cardinal points is by means of the angle at the sun, between the spring equinox and the perihelion. This angle is called the *heliocentric length of the perihelion.*

Though these explanations are too short to convey much to a reader not familiar with astronomy, they do, I hope, make it clear that the course of the earth around the sun is subject to slight periodical fluctuations, and that these fluctuations have an effect on the amount of radiation received by any particular part of the earth's surface. It should be realized that these fluctuations are merely fluctuations in the distribution of solar radiation over the latitudinal zones of the earth and in the course of the seasons. The energy output of the sun is assumed to be stable throughout the period of time over which our investigation extends.

The astronomical theory of the fluctuations of the Pleistocene climate.

The perturbations must have existed for enormous periods of time. They were not confined to the Pleistocene, and it is futile, therefore, to expect that the astronomical theory can provide the cause of the Pleistocene Ice Age. It can, and does, explain the fluctuations of the Pleistocene climate, but it cannot answer the question why glaciation phenomena abound in the Pleistocene, whilst none are known from the Tertiary.

In this respect, most of the earlier workers on the astronomical theory were mistaken. They all set out to discover the cause of the Ice Age, and they were made confident in their quest when they noticed that the perturbations promised even to solve the riddle of the alternation of glacials and interglacials. But they failed in their main aim for the reason given, and also failed to account for the fluctuations of the climate *during* the Pleistocene, because of an inadequate combination of the obliquity, the eccentricity and the precession.

Theories of Croll and Ball. This applies also to the theory put forward by Croll (1875), which constituted a great advance on the earlier theories and, therefore, became very popular for a time. It was abandoned eventually because it demanded a strict alternation of glaciations on the northern and southern hemispheres and an increase of glaciation in periods of cold winters. It suffered from overstressing the changes in eccentricity and precession, the fluctuations of the obliquity being treated independently. Ball (1892) succeeded in combining all three elements, but he considered their *total* effects on the two hemispheres only, which are very small.

It is not surprising that these and other attempts to construct an astronomical theory were considered as unsatisfactory. Apart from a few isolated revivals, the matter rested more or less for about twenty years. The chief difficulty, not realized, of the earlier workers was that they relied on qualitative arguments. The solution could not be found until the quantitative effects of the perturbations had been computed mathematically in a form suitable for climatic interpretation.

Calculation of the radiation changes. Fortunately, the mathematical aspects of the problem were attacked afresh while the fight over the theory was abating, and results were produced which made the theory appear in a new and clearer light.

The mathematical work involved in the calculation of the numerical effects of the perturbations is enormous. It is further complicated by the necessity of producing separate sets of figures both for zones of geographical latitude and for the seasons.

It would lead too far afield to go into the history of this work here (see Zeuner, 1944, Chapter V). It was begun by Lagrange in 1782, greatly advanced by Leverrier (chief publication in 1843), taken up again by Stockwell who, after 10 years of labour, published

new calculations of the perturbations in 1873. The results were for the first time tabulated over a long interval of time and with a view to climatic interpretation by Pilgrim in 1904. Finally, the numerical material was once more computed, after numerous improvements in method and interpretation, by M. Milankovitch (since 1913; main publications 1920, 1930, 1938). This author originally relied on Stockwell's formulae. In the course of about twenty years he supplied tables for every tenth degree of latitude of both hemispheres, and for the summer and winter halves of the year separately, covering the last million years.[1] The figures contained in these tables no longer give separately the effects of the three perturbations, but their combined effects in terms of heat radiation received at the upper limit of the atmosphere. Thus, an undisputable factual basis was at last secured for the re-interpretation of the influence of the perturbations on the terrestrial climate.

More recently, Milankovitch, in conjunction with Michkovitch, calculated a new set of tables, this time based on Leverrier's formulae. The reason for doing so was twofold; the new calculation provided a most important check on the first, the two being based on different mathematical premises, and it also promised more accurate figures, since Leverrier's basic values are nearer those obtained by recent measurements than are Stockwell's. But the two sets of figures agree so closely that, for general purposes, their differences can be regarded as negligible.

Necessity to consider latitudinal and seasonal differences. From what has been said it should be clear that, in interpreting fluctuations of solar radiation climatologically, it is necessary to consider both the climatic zonation and the seasons.[2] The latitudinal differences in radiation have been neglected in the past by many workers, and even in recent years by some who used Milankovitch's numerical results.

The consideration of the winter half of the year has been neglected even more. It has become almost a custom to regard the curve of summer radiation as *the* radiation curve, and consequently to forget the influence of the radiation received during the second half of the year. Workers who take the whole year into account are still few (notably Beck and Wundt).

The reason for this omission is easily understood. For simple

[1] Between 600,000 and one million years, the possible error increases rapidly to about 10 per cent. For this reason, tables and curves are usually given for 600,000 years only.

[2] 'Summer' is henceforth taken to comprise spring + summer; 'winter', autumn + winter, the year being divided into two halves *with equal number of days.* Thus a summer half and a winter half of the year are obtained which are of equal length, and therefore comparable with each other. Also these *caloric half-years* are constant in the course of time, so that they can be compared over any interval of the time-scale. The introduction of this device is one of the merits of M. Milankovitch.

graphical representation, the winter curve, which is almost the obverse of the summer curve, can be neglected. This simplification implies that one knows that when the summer curve shows a maximum of radiation, the winter curve (not drawn) has a corresponding minimum, and vice versa. Moreover, it is the summer radiation on which the melting of glaciers largely depends. The first climatologists to apply radiation curves to the Pleistocene (Köppen and Wegener, 1924), therefore, had reason to select the summer curve for their purposes.

Glacial phases correlated with phases of low summer radiation. This use of the summer curves as a *pars pro toto* is legitimate provided it is clearly kept in mind that a maximum of radiation on such a curve implies a minimum in winter, in other words, the maxima of the summer curve indicate phases of increased seasonal differences in radiation, and the minima decreased seasonal differences.

As we are concerned chiefly with the chronological aspects of the fluctuations of solar radiation, and not with the climatological side, it must suffice to say that, in temperate Europe, the phases of low summer and high winter radiation favour the formation of ice-sheets in the high mountains, i.e. in Scandinavia and the Alps. The mild winters mean increased snowfall in such areas, and the cool summers reduce melting. Thus it may be supposed that glacial phases are directly correlated with phases of low summer radiation, and that the curve of summer radiation of a suitable degree of latitude (for instance 65° N. for the 'centre' of the Scandinavian ice-sheet) gives a fairly accurate picture of the oscillations of this ice-sheet (fig. 48). The climatological background of the astronomical theory is discussed in greater detail in Zeuner (1944, p. 150 ff.).

Units used in expressing changes of radiation. In studying tables and curves, the reader will find a variety of units employed in denoting the intensity of radiation. The shape of the curve is, of course the same whatever unit is used, only the vertical scale being affected.

The first curves published (Köppen and Wegener, 1924) expressed the fluctuations in a *imaginary* displacement north or south, of the degree of latitude considered. Taking the 65th degree of northern latitude, for instance, it is shown to have received, some 10,000 years ago, a summer radiation as great as that now received by 60° N. On the other hand, 230,000 years B.P.,[1] the 65th degree had a great deficit of summer radiation, since it received an amount equal only to that received by 77° N. at the present day. This method of representation has its advantages in providing the climatologist with a good relative measure of the intensity of radiation changes. But to the non-climatologist it is apt to be misleading, partly because

[1] 'B.P.' short for 'before Present', meaning years as given in the radiation tables, counting backwards from A.D. 1800.

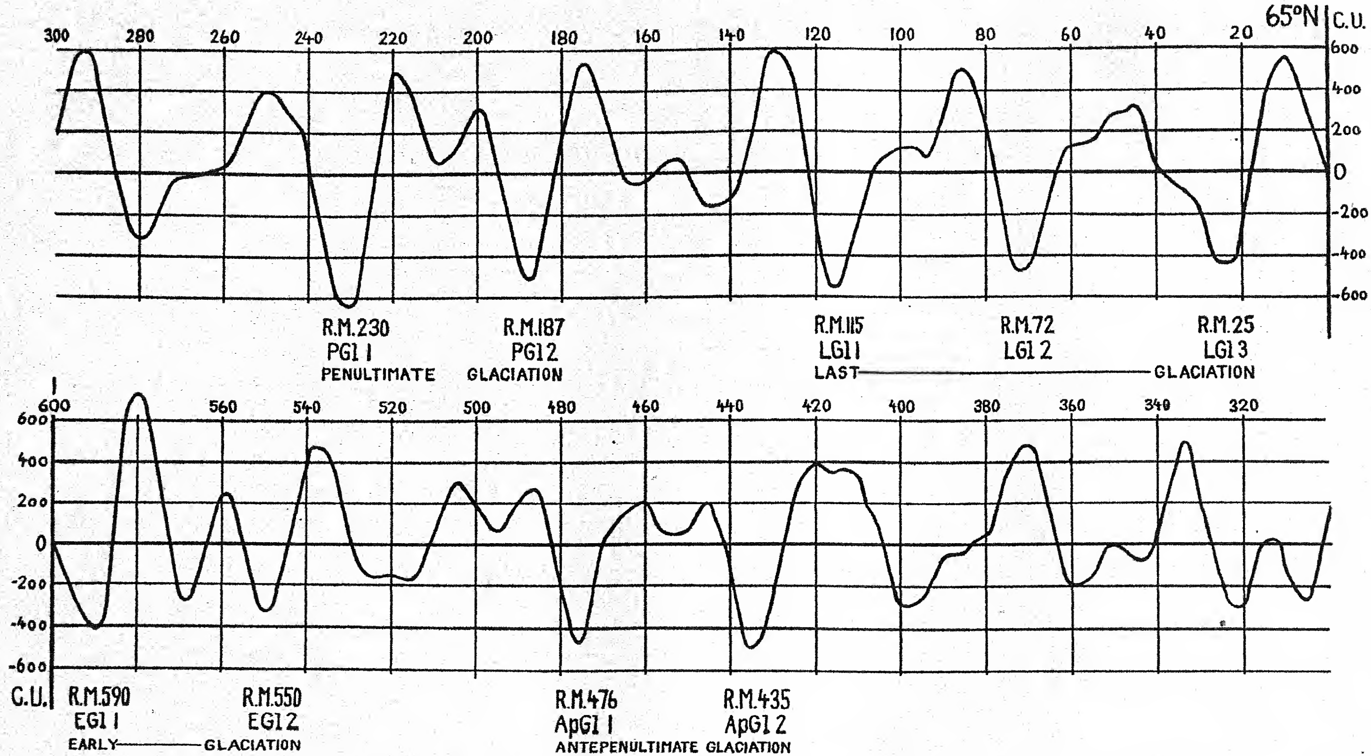


FIG. 48.—The detailed curve of solar radiation in summer, for 65° N. lat. Based on tables in Milankovitch (1930). Scale in canonic units.—From Zeuner, 1944.

the imaginary shift in winter is opposite to that in summer, and partly because in the remainder of Köppen and Wegener's book supposedly real changes of geographical latitude, due to a shift of the poles, are discussed. An instance of this type of curve is given in fig. 49.

Since the tables are expressed in units which have a direct relation to the average amount of radiation received by the earth from the sun (i.e. to the *solar constant*), expressed in calories, it appears better to use these in the graphs also (fig. 48). They are called *canonic units* and are obtained by substituting 1 for the value of the solar constant and 100,000 for the sidereal year.

Other graphs show the theoretical change in temperature which may be deduced from the change expressed in canonic units. There is, however, a wide divergence of opinion on this matter. While

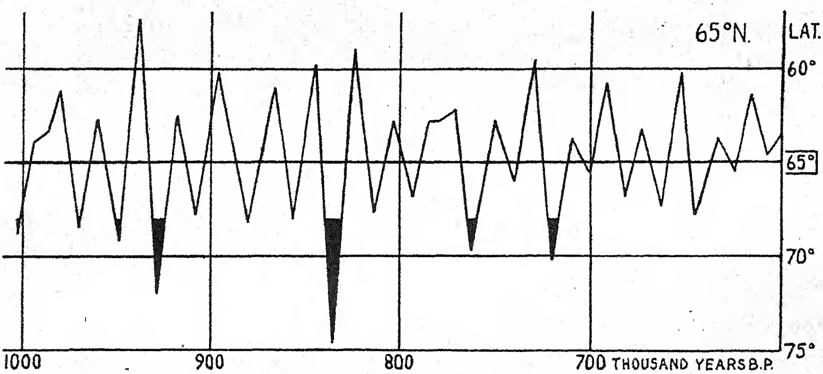


FIG. 49.—Extension of the radiation curve (fig. 48) to one million years B.P., showing amplitudes of summer radiation. Calculated by Milankovitch (1930).—From Zeuner (1944).

Milankovitch accepts a value as high as 1° C. per 150 canonic units, Simpson (1940) prefers values which are only about one fourth as great. Whether the influence of the fluctuations of solar radiation on temperature actually is great or small, is probably impossible to calculate. It is, from our point of view, better to use the empirical method of comparing the radiation curve with the climatic succession as revealed by geology. If there is sufficient agreement found, we may rightly assume that this influence must have been considerable.

A fourth scale which has been applied in the graphs is that expressing the vertical displacement (in metres) of the snowline in the mountains. Milankovitch (1938) found that, theoretically, one canonic unit should correspond to a displacement of the snowline of 1·09 metres. In nature, great deviations from this value must be expected.

Summary. Thus, the modern version of the astronomical theory of the Ice Age does not claim to provide a cause for the Ice Age as such, but it does answer the question why there were glacial phases separated by mild, interstadial or interglacial, phases. The former are regarded as caused by periods of low summer radiation and high winter radiation, the latter by periods either of moderate conditions (as to-day) or by high summer and low winter radiation, which give the climate a continental character but do not favour the formation of ice-sheets.

In applying the theory to observed geological sequences, curves for the summer radiation only are the most suitable means, but it must be borne in mind that the geographical latitude has to be taken into consideration.

Other complications, such as the influence of geomorphology, the secondary climatic effects of an ice-sheet, and the *retardation* of the maximum of the glacial phase relative to the minimum of summer radiation which caused it, need not be discussed here. For chronological purposes it is sufficient to compare the radiation curves with the geological record, and to decide whether or not agreement is close enough to imply a causal connexion. If it is, then the curves provide a time-scale in years which can be used in the dating of geological events as well as in the prehistory of man, with the proviso that certain corrections will have to be applied in the future when we are able to assess more correctly the effect of retardation.

C. THE AGREEMENT OF THE GEOLOGICAL RECORD WITH THE FLUCTUATIONS OF SOLAR RADIATION, AND THE ENSUING ABSOLUTE CHRONOLOGY

If one selects the radiation curve for 65° N., 55° or 45° N. lat. (they resemble each other closely), and compares the sequence of minima of summer radiation with the sequence of glacial phases in Europe as established by geological methods, one is struck by their similarity. Going backwards into the past, the radiation curve for the last 600,000 years (fig. 48) shows a series of three summer minima between 25,000 and 115,000 years B.P., then an interval of some 60,000 years of more or less normal conditions, before this a couple of minima at 187,000 and 230,000 B.P., preceded by a long interval devoid of intense minima and lasting about 190,000 years. Prior to this, we find another couple of minima at 435,000 and 476,000 B.P., preceded by an interval of some 60,000 years, and this by a couple of minima (more pronounced in the curve based on Stockwell) at 550,000 and 590,000 B.P.

In other words, the succession of minima of summer radiation exhibits precisely the same peculiar rhythm as does the sequence

of glacial phases (p. 134), namely, beginning with the earliest: two, short interval, two, long interval, two, short interval, three. It seems very difficult to dispose of this coincidence by calling it accidental.

Detailed comparison of radiation and climatic phases. On the other hand, one would not expect the glaciations to reproduce every minor detail of the fluctuations of radiation. Yet, some agreement is evident even in the lesser features.

One of the characteristics of the relative chronology is the evasiveness of the Early Glaciation. Geological evidence suggests that it was a smaller glaciation than the later ones. The summer minima of the radiation curve which can be matched with Günz of the Alps are, indeed, considerably weaker than those of the later glaciations.

Furthermore, the extension of the radiation curve to one million years B.P. (fig. 49) provides some minima which might correspond to the three Donau Phases found by Eberl to precede Günz in the Alps. This author correlated them with three minima between 680,000 and 760,000 B.P. Although this correlation is somewhat arbitrary, since there are earlier summer minima which were more intense, it shows at least that fluctuations of solar radiation did occur before 600,000 B.P. which could well account for the cold phases found to precede the Early Glaciation.

The division of the Last Interglacial by a cool oscillation accompanied by the drop in sea-level which separates the Main and Late Monastirian shore-lines, finds its counterpart in the division of the interval between the minima of 115,000 and 187,000 by a weak phase of low summer radiation around 145,000 B.P. This agreement is extremely suggestive.

Similar cool oscillations are claimed to have interfered with the course of the Great Interglacial. The radiation curves here afford no fewer than five weak, but fairly pronounced, minima. Geological evidence has so far made probable that there were at least two cool phases. It will need a great deal of good luck to find evidence for a succession of five weak phases of deterioration of climate during the Great Interglacial, since it is unlikely that unambiguous sections containing such evidence are preserved in any one area.

Agreement of radiation curve with Penck's curve and estimate. Apart from this high measure of agreement between the geological record [1] and the radiation curve, a strong argument for the applicability of the astronomical time-scale can be derived from Penck's estimate for the Pleistocene (p. 134). Penck could not know the duration of the glaciations, but his estimates for the mild

[1] Much of the detailed chronology had been established *before* the first radiation curve was published.

phases, and for the total duration of the Pleistocene, are excellent indeed:

	Penck's estimate	Radiation curve
Time since LGl_3	24,000	22,000
Duration of LIgl	60,000	60,000
Duration of PIgl	240,000	190,000
Duration of ApIgl	60,000	60,000
Duration of Pleistocene	600,000	600,000

Considering that Penck extrapolated from the 20,000 years of the 'Postglacial' of Switzerland, one cannot but conclude that measurement of time by processes of sedimentation and weathering might afford rather greater opportunities than is generally believed.

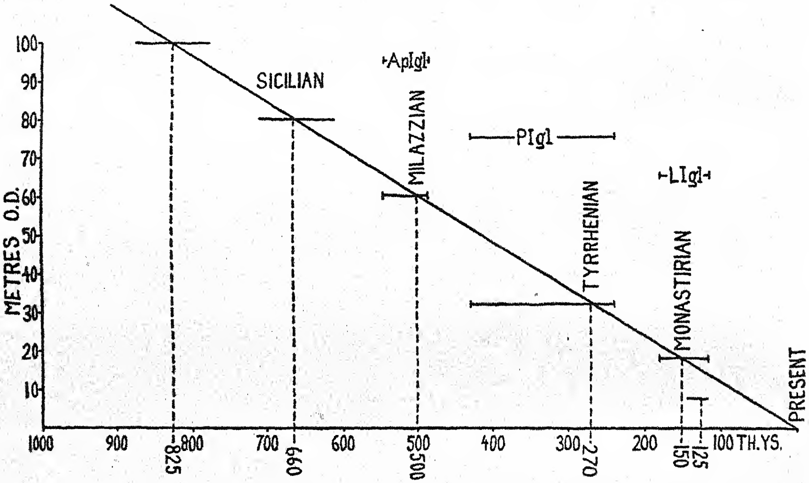


FIG. 50.—Diagram showing the relation of altitude to time for the high sea-levels of the Pleistocene. The horizontals representing the Main Monastirian, Tyrrhenian and Milazzian levels have the length of the corresponding interglacials on the time-scale.—From Zeuner (1944).

This agreement of Penck's estimate with the radiation dates strengthens greatly our case for an absolute chronology of the Pleistocene. If such similar results are obtained for the durations of the mild periods by such different methods, and if the geological record reveals the same number of cold phases as the radiation curve comprises major summer minima, the astronomical time-scale can confidently be applied in dating the glacial phases. The retardation of the glacial phases relative to the minima of summer radiation which initiated them, cannot have been great.

One is justified, therefore, in using 'radiation dates' for the glacial phases, bearing in mind that certain displacements in time are neglected. But the error due to this factor is not likely to have exceeded 20 per cent. for LGl_3; it becomes smaller for the

earlier phases, being less than 5 per cent. for the Penultimate and earlier glaciations.[1]

Sea-levels and radiation curve. A very interesting result is obtained if the heights of the interglacial sea-levels are plotted on the astronomical time-scale (fig. 50). One then finds that they can be connected by a straight line (see Zeuner, 1944, p. 249). It seems probable that this straight line represents a more or less *continuous* drop of sea-level in the course of the Pleistocene, on which the oscillations due to glacial eustasy were superimposed.

Summary. Table of dates. Combining the geological evidence with the astronomical time-scale by means of the radiation curves, an absolute chronology is obtained which can be regarded as sufficiently reliable for the purposes both of palaeoclimatology and prehistoric archaeology. In the accompanying table (fig. 51), geological events

Phase	Radiation date, in years B.P.	Duration, in years
Time since Last Glaciation, phase 3		22,000
Last Glaciation, phase 3, climax	22,100 (55° N.) 25,000 (65° N.)	
Last Glaciation, phase 2, climax	27,000	
Last Glaciation, phase 1, climax	115,000	
Last Interglacial, duration		60,000
Late Monastirian high sea-level	125,000	
Cool oscillation of Last Interglacial	145,000	
Main Monastirian sea-level	150,000	
Penultimate Glaciation, phase 2	187,000	
Penultimate Glaciation, phase 1	230,000	
Penultimate Interglacial, duration		190,000
Tyrrhenian high sea-level	270,000	
Antepenultimate Glaciation, phase 2	435,000	
Antepenultimate Glaciation, phase 1	476,000	
Antepenultimate Interglacial, duration		60,000
Milazzian high sea-level	500,000	
Early Glaciation, phase 2	550,000	
Early Glaciation, phase 1	590,000	
Plio-Pleistocene boundary	600,000	

FIG. 51.—The absolute chronology of the climatic phases of the Pleistocene. Compare with fig. 47.

which can be dated are compiled, and their approximate dates and the duration of certain periods given. Though many adjustments will be made necessary by future research, the story revealed by the 'calendar' of the Pleistocene is extremely consistent.

[1] These figures are based on estimates for the amount of retardation. See Zeuner (1944, p. 160).

CHAPTER VI

PALAEOLITHIC CHRONOLOGY OF TEMPERATE EUROPE

A. INTRODUCTORY REMARKS

With the detailed chronology developed in the preceding chapter at our disposal, we are in a position to elaborate a detailed archaeological chronology, to which the absolute time-scale, taken from the radiation curve, can be applied. The results obtained in this manner may be meagre, since only such prehistoric sites can be fitted into the detailed climatic chronology as can be closely dated on geological and/or palaeontological grounds.

Our method of developing a detailed chronology of the Palaeolithic, therefore, differs essentially from the practice of Palaeolithic chronology which has been in vogue in recent years, namely that of using the implements as zone-fossils. This practice may work well in many cases, but the successes are apt to obscure the fact that the cart is being put before the horse, the precise geological age of the industries being assumed as known (often on very flimsy or even incorrectly interpreted evidence), and this assumption being used to determine the age of the deposit containing the industry.

If we are to obtain a clear idea of the sequence, overlap, alternation and duration of the industries of the Palaeolithic, it is absolutely necessary to keep apart the geological (and palaeontological) evidence for the climatic chronology from the typological classification of the industries of early man. In order to do so, the evidence for the climatic, and incidentally the absolute, chronology of the Pleistocene has been published separately (Zeuner, 1944), and summarized in our Chapter V, Part A, so that we can now proceed to search for Palaeolithic sites which can be dated on non-typological evidence. These will in turn be used in developing the chronology of the Palaeolithic.

Unfortunately, sites of this kind are few. Most of the classic localities, such, for instance, as the caves of the Dordogne, were excavated before the days of modern Pleistocene stratigraphy, and the published sections are insufficient for our purpose.

In other instances, the very thorough work of the excavators has, for the time being, not provided the kind of climatic evidence necessary for placing the site in the detailed chronology. Many famous sites have had to be discarded for this reason. This is the more deplorable as often a re-inspection of the section and a small amount of analytical work on certain strata would have settled the matter. I am alluding to many sections in which buried soils, solifluction layers and loesses are suggested in vague terms, and

which, if only the climatic character of the deposits had been studied by an expert, could definitely be fitted into the detailed chronology. I may conclude these somewhat destructive remarks by saying that they are based on the scrutiny of a very large amount of published and unpublished material, including the well-known Palaeolithic sites from all parts of the world, and temperate Europe in particular. It is impossible in a book like the present one to discuss the reasons why certain sites have not been regarded as chronologically important. But a few sites have been mentioned which, though at the moment indecisive, promise in the future to fill certain gaps in the chronology of the industries.

Furthermore, I would suggest that the environmental and palaeoclimatic aspects of archaeological stratigraphy should be granted greater prominence during the excavation. Much has been done in this respect in recent years, but more remains to be done, especially under the supervision of workers trained in this particular line of work.

The reader, therefore, will miss many famous sites in this and the following two chapters, but those treated, though often less spectacular from the typological point of view, do provide us with the required chronology. In Europe, at any rate, all the major industries can be placed in the climatic chronology, while the age of some variants of these industries is still uncertain. The most deplorable instance of the latter kind is the High Lodge industry of East Anglia, often called Clactonian III, which can be either Penultimate Interglacial or Last Interglacial.

The material is arranged regionally, central Europe (with a few remarks on east Europe and Siberia) being taken first (Part B), then the important region of northern France, with the Channel Islands, and a few remarks on Portugal (C), and lastly the British Isles (D). The ensuing relative and absolute chronology of the Palaeolithic of temperate Europe is finally discussed and tabulated in the Summary (E).

B. PALAEOLITHIC OF CENTRAL EUROPE, EAST EUROPE AND SIBERIA

Palaeolithic in the area of the Scandinavian glaciations. Palaeolithic sites are comparatively rare in the morainic areas of north, central and east Europe. Repeated transgressions of the ice destroyed or covered the traces which early man may have left during the interglacial and interstadial phases, and most localities belong to cultures contemporary with the various stages of the Last Glaciation. In the peripheral zone, however, conditions were more favourable, and a good many Palaeolithic sites are known from river gravels, glacifluvial gravels and loess covering moraines. It is often difficult to decide whether such sites should be regarded as belonging to the morainic zone or to the periglacial zone. Some overlapping

is unavoidable; the selection of sites mentioned is somewhat arbitrary, but the following paragraphs and those on the Palaeolithic of the periglacial zone (p. 156 ff.) supplement one another.

The stratigraphical position of Palaeolithic sites of north Germany has been reviewed by Woldstedt (1935*a*), and a book on the subject, by J. Andrée (1939), describes the known sites and their industries. Unfortunately, Andrée considers the German Palaeolithic as highly individualized and as the product of continuous local evolution. It is often difficult, therefore, to compare the German industries with those of west Europe from the typological point of view.[1] Generally speaking, however, both Andrée's and Woldstedt's chronological results are consistent with those obtained in other areas (compare table, fig. 65).

No Abbevillian (= Chellian) or Acheulian has been found in the formerly glaciated areas of central and east Europe, most certainly not in a stratigraphically definite position.

Oberwerschen (*cf. Clactonian or Levalloisian*). The earliest known, datable, site is Oberwerschen, in the Weissenfels district, central Germany. It was studied by Bicker and Röpke. Since their publication has not yet been available to me, I rely on Andrée (1939). The section is as follows:

0·75 m.	Loess
0·6 m.	Boulder-clay
2·0 m.	Sand
5·0 m.	Gravel of local or southern origin, but Scandinavian erratics present. With implements.
2·0 m.	Sand, probably derived Tertiary.

The site lies far outside the areas of the glacial phases Weichsel and Warthe, and the implementiferous gravels are covered by a bottom moraine. The gravels are fluviatile, yet they contain some pebbles of Scandinavian origin which can be derived only from deposits of an earlier glaciation. This was, therefore, Elster, and the glaciation following the gravels, Saale. The gravels thus appear to date from the Elster-Saale interglacial.

Typologically, Oberwerschen is described as an industry with 'hand-points'; it is a flake industry reminiscent in some respects of Clactonian, and of Levalloisian in others.

Wangen. At Wangen on the Unstrut, in Thuringia, implements were found in the 'Wangen terrace', the first terrace formed after the Elster Glaciation, which reached the district (Lehmann, 1922). They comprise a primitive 'boucher', 'hand-points', and long and round scrapers. Authors have usually avoided classifying them by

[1] It is, of course, well known that, the farther east one goes, the more difficult the typological comparison becomes. But this does not render a comparison unnecessary.

the French terminology, and the practice of calling the Wangen industry ' Chellian ' is due to the assumption prevailing in Germany that the ' Chellian ' is the industry of the Penultimate, or Great, Interglacial.[1] Woldstedt (1935*a*) writes regarding Wangen (translated, with my italics): ' Wangen thus appears to be the only north German site which *perhaps* would have to be assigned to the Elster-Saale interglacial and which *therefore* would be of Chellian *age*.' This is a good example of confusion of geological and archaeological conceptions. The age is meant to be Elster-Saale interglacial, and since the Chellian is believed to occur elsewhere during this phase (which, by the way, is not correct), the chronological phase is called by the industry, a dangerous and misleading practice. There is no typological foundation for considering Wangen as ' Chellian ' ; it belongs to the same class of industry as Oberwerschen. Oakley compares it with a developed Clactonian (see p. 189), but Grahmann (1937) points out that there are indications of prepared striking platforms. Geologically, it is certainly later than the Elster Glaciation and earlier than Saale, and the Wangen terrace probably was aggraded during the first cool phase of the Penultimate Glaciation.

Markkleeberg (*Levalloisian*). At Markkleeberg near Leipzig (Grahmann, 1935) an interesting industry was found in glacifluvial gravels formed during the advance of the Saale ice-sheet (i.e., PGl_2) the boulder-clay of which covers the gravels in two separate layers corresponding to two local oscillations. The industry was formerly regarded as Acheulian (or anything from Chellian to Mousterian), but Breuil and Obermaier now consider it as middle Levalloisian (Lev. III–IV). This industrial stage appears in France at about the same time. Grahmann (1937), who has studied the specimens, says they are ' predominately typical of the lower Levalloisian ', but ' some specimens show Clactonian technique '. A small number of *derived*, typical Clactonian implements have been found also.

Hundisburg (*cf. Levalloisian*). Hundisburg near Neuhaldensleben, Saxony prov., north Germany, has by some been considered as an Acheulian site. The specimens are not characteristic enough to allow of a correlation with French types. Schmidt (1912) denied their Acheulian affinities but found that some flakes were reminiscent of Levalloisian. Andrée assigns Hundisburg, as well as the three afore-mentioned sites, to his ' hand-point ' culture. Grahmann (1937) has recognized a primitive Levalloisian technique on most specimens. The geological section of Hundisburg (Schmidt, 1912 ; Wiegers, 1928) is as follows :

[1] In Zeuner (1935*a*) the ' Chellian ' (now Abbevillian) appeared, with a question mark, in the Elster-Saale interglacial, in order impartially to express the view of German writers. This is now proved to be incorrect ; the Abbevillian is restricted to the Antepenultimate Interglacial.

0·75 m. Sandy loess with humus
0·2 m. Loamy sand with humus
———unconformity (stone bed)———
0·5–2·5 m. Upper boulder-clay
2·8–3·8 m. Sand and gravel, fluviatile, with shells, bones (*Elephas primigenius*, *Tichorhinus antiquitatis*, &c.), and implements
0·6–1·0 m. Lower boulder-clay
resting on black Tertiary clay.

The implementiferous gravel contains mammoth and woolly rhinoceros and, therefore, must correspond to a fairly cold climate. According to Woldstedt, this phase was the beginning of the Saale Glaciation. Hundisburg and Markkleeberg thus appear to be contemporaneous.

Makau (*Levalloisian*). At Makau, Ratibor district, Upper Silesia, Lindner (1937) found implements which he considers as closely related to those of Markkleeberg. To judge by his figures they may well be classified as middle Levalloisian. They occur in glacifluvial gravels underneath a boulder-clay of the Saale Glaciation,[1] i.e. in the same stratigraphical level as those of Markkleeberg.

Mousterian. No Mousterian or mousterioid industry has so far been described in north Germany from a geological section which is so clear that it admits of one interpretation only. There are several sites which, typologically, may be classified as mousterioid and, geologically, range around the Warthe Phase. For details, I refer to Andrée's book (1939), in which they appear as ‘ hand-point ’ cultures.

Kozlowski (1925) placed industries of Micoquian and La Quina (Mousterian) affinities found in caves north of Cracow, Poland, at the beginning of the Weichsel Glaciation. The Warthe Phase, however, had at that time not yet been separated from the Weichsel Glaciation.

Thus, in the formerly glaciated area of central Europe the interval between Saale and Weichsel is still to be regarded as a chronological gap from the archaeological point of view.

The deposits of the Weichsel Glaciation and its equivalent loess, however, have provided a number of Upper Palaeolithic sites. Only a few can be mentioned here.

Upper Palaeolithic of Upper Silesia. The geological age of upper Palaeolithic sites in Upper Silesia has been studied by Lindner (1937). Most localities are in the Leobschütz district and in the adjacent Opava (Troppau) district of Czechoslovakia, close to the south-eastern end of the Sudeten Mountains. They are all connected with the Younger Loess which is superimposed on boulder-clay or

[1] As regards the age of the boulder-clays of Upper Silesia, compare Zeuner (1932) and Bau (1938).

glacifluvial gravels of the Saale Glaciation. The Younger Loess of Silesia corresponds to the second Younger Loess of west Germany and France and can be traced from south of the Weichsel moraines (Brandenburg phase) across the moraines of the Warthe Phase to Upper Silesia. Remnants of the first Younger Loess are extremely rare (Weinberg section near Katscher; Communal Brickyard at Opava; Karlsberg on the Zobten, Lower Silesia).

At Kösling, Leobschütz district, implements occur which Lindner compares with the earliest Aurignacian of Moravia, the Šipka stage. In Moravia, this industry occurs at the base of the Younger Loess in the Pekárna Cave, where it is called primaeval or primitive Aurignacian, or Pseudomousterian, by Absolon and Czižek (1932).[1]

Lindner was unable to study the Kösling section which has been destroyed. At no other place in Upper Silesia has this industry been studied in situ, so that it is worth while to reproduce here, from my diary, the section as it appeared on a visit in 1929 (fig. 52). The implements occurred in a stratified sand with pebbles and an admixture of loess, which appeared to me to be nothing but Younger Loess contaminated by sludge or solifluction. This was the early part of the Weichsel Phase.

Two further important sites are at the Schwarzer Berg ('Black Hill') near Dirschel, Leobschütz district. In the Thröm pit, implements of the Willendorf stage (developed Aurignacian, 'eastern Gravettian') were recovered *near the base* of the typical Younger Loess, which rests on contorted glacifluvial gravels of the Saale Glaciation. In the main pit, the section is the same, but implements occur in the *middle portion* of the loess which is about 6 feet thick and are of an early Solutrian type, with affinities to the Moravian site of Předmost, where, according to Lindner (1937, p. 36), following Wiegers, the same industry is found in the same geological position.

A late Aurignacian, with Magdalenian affinities and with backed blades of the La Gravette type, was found at Janken, Ratibor district. The specimens still occurred in the loess, but at so high a level that they were brought up by the plough.

These localities supply an interesting succession of relative dates for Upper Palaeolithic industries. The Younger Loess 2 being the equivalent of the Weichsel Glaciation, the 'primitive' Aurignacian of Upper Silesia proves to be of early Weichsel age, part of the eastern Gravettian of early-maximum, the early Solutrian of maximum, and a Gravettian with Magdalenian affinities of late Weichsel age. All these, however, fall at the time when the climate was sufficiently glacial for loess to be formed. The latest Aurignacian

[1] It is obvious that the exact significance of these typological terms has to be tested in the light of the more recent views concerning the early Aurignacian of western Europe.

(cf. Gravettian) of the loess area appears to be contemporary with the Magdalenian elsewhere.

Magdalenian in north Germany. The stratigraphical position of the Magdalenian of north Germany (Menzel, 1914) is the same as in the periglacial and alpine areas. The sites in the district of the River Havel west of Berlin are situated inside the terminal moraine

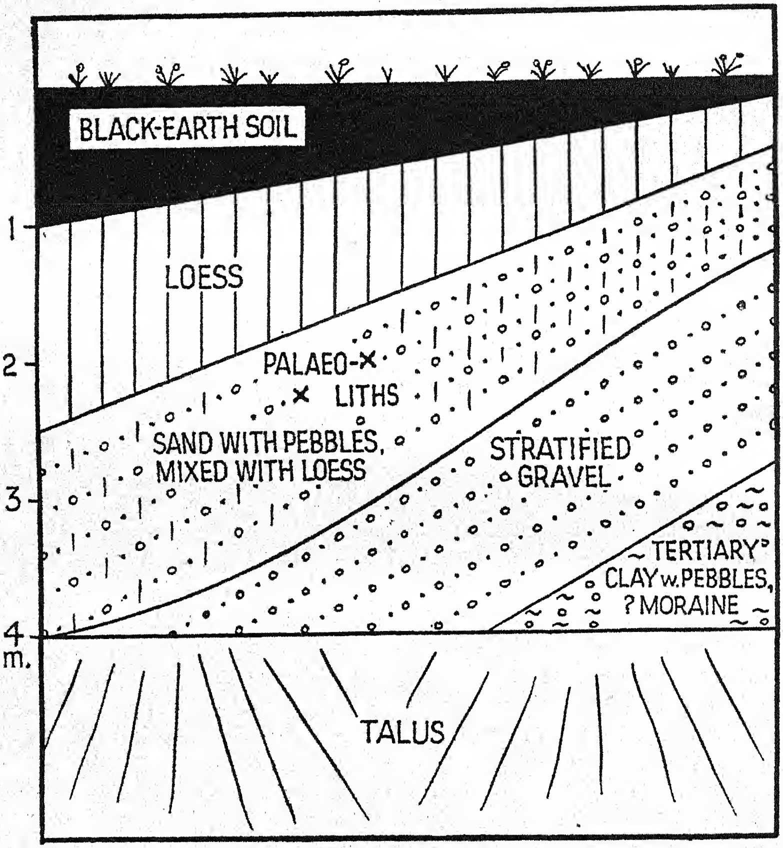


FIG. 52.—Loess section of Kösling near Katscher, Upper Silesia.

of the Brandenburg stage. This being the maximum of Weichsel, the Havel Magdalenian must be later than this, though perhaps only slightly.

Meiendorf. As a late Magdalenian site, Meiendorf may be recalled. It has been described in connexion with varve chronology and pollen analysis (p. 72). It is associated with deposits of the Pomeranian phase and is the latest occurrence of the Magdalenian which, soon after the climax of the Pomeranian, was replaced by, or developed into, Mesolithic (p. 162).

Palaeolithic of north Germany, summary. The following table will help in comparing some of the Palaeolithic sites of north Germany with those of other areas :

Glacial Phase	Locality	Industry
Pomeranian	Meiendorf	Magdalenian
	Janken, ? Havel	Gravettian, Magdalenian
Weichsel	Dirschel Thröm Kösling	early Solutrian Gravettian ' primitive ' Aurignacian
Warthe		
Saale	Markkleeberg, Hundisburg, Makau, Wangen	Levalloisian, ' hand-point ' culture
Great Inter-glacial	Oberwerschen	' hand-point ' culture (? cf. Levalloisian or Clactonian)
Elster		

Palaeolithic of the Alpine area. Before proceeding to the peri-glacial zone, a few words must be said about the Palaeolithic of the Alpine area of glaciation which has provided us with some valuable chronological evidence with regard to the Magdalenian.

Palaeolithic of Switzerland. Beck (1939) has studied the geology and climatic conditions of the Lower Palaeolithic sites of Switzerland some of which are notable for the altitude in which they are situated inside the high mountain valleys (Wildkirchli cave, 4,923 feet; Drachenloch cave, 8,150 feet, both in the Säntis Range, northern Switzerland; Baechler, 1929, 1930), whilst another site is famous for its abundant and well-studied fauna of mammals (Cotencher in the Jura Mountains; Dubois and Stehlin, 1933). Beck found that they all date from the second part of the Last Interglacial (fig. 53).

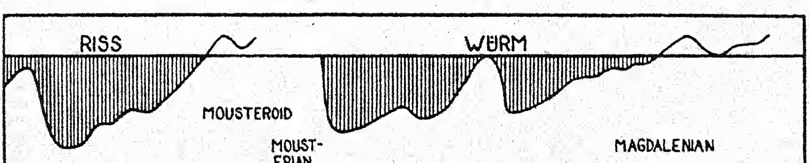


FIG. 53.—Glaciation curve for northern Switzerland, constructed by Beck (1939), and relative position of Palaeolithic industries. The third phase of the Last Glaciation is probably much under-rated, judging from the evidence obtained in the Lake Constance area.

Cotencher is a site with typical Mousterian, whilst the high Alpine stations may best be described as mousterioid, according to Obermaier. These results of Beck agree well with the age of the Mousterian of Ehringdorf and other sites (see p. 159).

Magdalenian of Lake Constance area. The upper Palaeolithic is represented in the famous Kesslerloch cave, near Schaffhausen, a little west of Lake Constance. It is closely connected with the terminal moraines of Würm. Among others, it was studied by Penck (1901) and Heierli (1907). Soergel (1919) divided the deposits of the Kesslerloch into three phases, the earliest of which contains a cold fauna and an early Magdalenian. In the middle layer, musk-ox and woolly rhinoceros are absent, but beaver and roe-deer appear instead. These indicate that forests had spread. The industry is a developed Magdalenian. The fauna of the uppermost horizon is again colder, beaver and roe-deer having disappeared. Its industry is regarded as late Magdalenian by R. R. Schmidt.

It is evident that, during the time of Magdalenian occupation of the Kesslerloch, the climate was decidedly cold at first, then milder, and then once more colder for a time.

The connexion of these fluctuations with morainic stages was rendered possible by Schmidle's studies (1914). The Kesslerloch lies just at the margin of the Schaffhausen moraine (Würm 1). When the ice was standing at the Diessenhofen moraine (Würm 2), about 5 km. farther east, the site was not yet habitable, and therefore the lower cold level can at the earliest date from the retreat of Würm 2. The upper cold level, therefore, can at the earliest represent the following belt of terminal moraines, that of Stein-Singen (Würm 3), and the milder intermediate bed an oscillation intervening between the two.

The importance of the Kesslerloch lies in the fact that its Magdalenian occupation must have begun *after* the maximum extension of Alpine Würm 2, though when the climate was still cold. It continued through a mild oscillation into the cold Stein-Singen phase which has been correlated with the Pomeranian by Woldstedt and others. This result agrees with observations in north Germany (p. 152) and the periglacial area (p. 161).

Glaciated areas of central Europe, Summary. The chronology of the Palaeolithic of the formerly glaciated areas of central Europe is summarized in fig. 54. The Alpine area has so far supplied evidence for the Mousterian and the Magdalenian only, but this agrees very well with that from the Scandinavian area. The most interesting feature is the rapid succession of upper Palaeolithic industries during the second phase of the Last Glaciation, and the subsequent persistence of the Magdalenian through the following interstadial to the climax of LGl_3.

The Lower Palaeolithic is scarce, but of interest, since there is a

Phase	Alpine Area	Scandinavian Area	Palaeolithic of Glaciated Europe	North American Area	N. American Stone-Age
PGL					
	ONE OF THE STAGES INSIDE THE MOUNTAINS	FENNOSCANDIAN MORAINE		?COCHRANE STAGE	
		WEICHSEL		WISCONSIN	FOLSOM
W3	ZÜRICH = SINGEN = ÖLKOFEN	POMERANIAN MORAINE	MESOLITHIC MAGDALENIAN	ST. JOHNSBURY MORAINE	
			MAGDALENIAN		
W2	b. SCHLIEREN = DIESSENH. a. KILLWANGEN = SCHAFFH.	b. FRANKFURT-POSEN a. BRANDENBURGIAN	MAGDALENIAN AURIGNACIAN SOLUTRIAN AURIGNACIAN	HARBOR HILL MORAINE	
				PEORIAN INTERSTADIAL	
W1	? ADVANCE PHASE OF EBERL AND KNAUER	FLÄMING OR WARTHE PHASE		IOWAN, ? = RONKONKOMA	
		SKÄRUMHEDE SERIES	MOUSTERIAN	SANGAMON INTERGLACIAL	
PW	LAST INTERGL.	DANISH BED III; LAST INTERGL.			
		EEM SERIES	HAND-POINT CULTS		
R2	LATE "OLD MORAINES" & LOWER HIGH TERRACE	SAALE MORAINE	MIDDLE LEVALL.	ILLINOIAN	
R1	EARLY "OLD MORAINES" & UPPER HIGH TERRACE				
	GLÜTSCH OF BECK; KANDER OF BECK; GREAT INTERGL.	GREAT INTERGLACIAL	HAND-POINT CULTURE	YARMOUTH INTERGLACIAL	
M2	LATE ALTTERRASSE	ELSTER MORAINE		KANSAN	
M1	EARLY ALTTERRASSE				
				AFTONIAN INTERGLACIAL	
G2	LOWER DECKTERRASSE	v. WERVECKE'S PRE-ELSTER MORAINES??		?NEBRASKAN	
G1	UPPER DECKTERRASSE				
	DECKENSCHOTTER				
D3	DONAU GRAVEL III				
D2	DONAU GRAVEL II				
D1	DONAU GRAVEL I				
S	STAUFENBERG GRAVEL				
O	OTTOBEUREN GRAVEL				

FIG. 54.—Chronology of climatic phases and Palaeolithic of the glaciated areas of northern central Europe, the Alps and North America.

suggestion that the Levalloisian technique first appeared in the Penultimate Interglacial. No light has been shed on the replacement of the Mousterian by upper Palaeolithic in the glaciated areas. There is a gap in the record extending over LGl_1 and $LGl_{1/2}$. The results may be summed up as follows:

(1) No Abbevillian (Chellian) or Acheulian has been found in the formerly glaciated areas.

(2) The earliest are flake industries reminiscent of the Levalloisian and Clactonian of west Europe. They occur during the

Penultimate or Great Interglacial and continue at least up to the maximum of Saale (PGl_2).

(3) (Lower or) Middle Levalloisian occurs in glacifluvial gravels near the extreme border of the Saale Glaciation, i.e. almost at the maximum of PGl_2.

(4) The Last Interglacial has yielded Mousterian and mousterioid industries in the Alps. They appear to date from the second half of this interglacial.

(5) Upper Palaeolithic is associated with Weichsel = Alpine Würm 2 (LGl_2). It appears early during this phase, with Mousterian

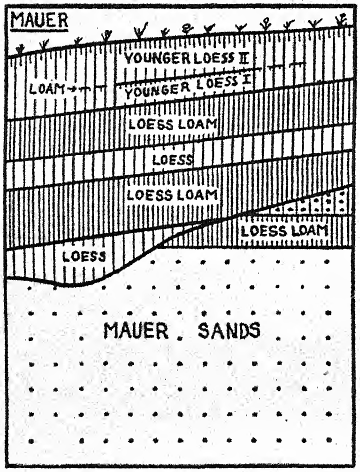


FIG. 55.—Loess section of Mauer near Heidelberg, Neckar Valley, west Germany. North wall of the section, which does not show the subdivisions of the fluviatile series but contains the entire loess succession. *Homo heidelbergensis* was found in the fluviatile 'Mauer Sands'.—After Soergel (1928) from Zeuner (1944).

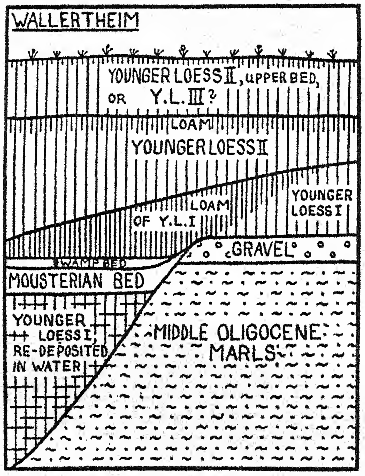


FIG. 56.—Section of Wallertheim, near Mainz, Rhine Valley, with three beds of loess separated by two weathering horizons, and a Mousterian occupation level in the Younger Loess I.—Based on Schmidtgen and Wagner (1929), from Zeuner (1944).

reminiscences, in Upper Silesia and Moravia ('Primitive' Aurignacian, Šipka stage). The Solutrian is confined to the maximum of Weichsel, and preceded and followed by Gravettian.

(6) The Magdalenian appears to have started immediately after the climax of LGl_2, and persisted through the mild oscillation separating LGl_2 from LGl_3, up to the maximum of LGl_3.

The periglacial area of central Europe. It is unfortunate that the river terraces of central Europe contain few artefacts. Thus, in spite of their importance for the detailed chronology of the Pleistocene, they offer little direct help in dating the stages of the Palaeolithic. But we are compensated by the great number of loess sections

which, in many instances, can be dated indirectly by the river deposits on which they rest. Sections consisting of loess and other non-fluviatile deposits have contributed most of the chronological evidence that we require. In addition, there are some composed of travertine (Ehringsdorf, p. 159) and some composed of solifluction deposits (Petersfels, p. 161). We shall consider first four sections from the Rhine Valley which, taken together, provide us with an outline of the archaeological chronology from the time of the Antepenultimate Glaciation onwards.

Mauer near Heidelberg. The first is Mauer, situated in the bow of an abandoned meander of the River Neckar, near Heidelberg (Soergel, 1928, 1933). It is the famous locality of *Homo heidelbergensis*. No stone implements have been recorded from here (presumably since collectors in early Pleistocene deposits are apt to look for hand axes, and consequently inclined to overlook primitive flake implements), but apparently worked bone has been found (Voelcker, 1933). The fluviatile sands in which the finds were made are covered by a great thickness of loess with weathering horizons (fig. 55). The succession, as found by Soergel, is the following:

Bed, and climatic character	Minimum age
(N) Recent soil: temperate	Postglacial
(M) Younger Loess II: cold steppe	LGl_2
(L) Weathering loam: temperate	Interstadial $LGl_{1/2}$
(K) Younger Loess I: cold steppe	LGl_1
(J) Weathering loam: temperate	Last Interglacial
(I) Upper Older Loess: cold steppe	PGl_2
(H) Weathering loam: temperate	Interstadial $PGl_{1/2}$
(G) Middle Older Loess: cold steppe	PGl_1
(F) Fluviatile sands, and weathering of these sands and of the Lower Older Loess: long temperate phase	Antepenultimate Interglacial
(—) Deposition of Lower Older Loess: cold steppe (E) Fluviatile sands subjected to solifluction: cold climate	$ApGl_2$
(—) Gap, due to denudation (D) Weathering horizon: temperate (C) Floodloam (B) Sandy calcareous floodloam (A) Mauer Sands.—(A)—(D), including gap: Temperate	Interstadial $ApGl_{1/2}$, or Antepenultimate Interglacial, late phase

This succession illustrates the type of loess section in which periods of deposition of loess alternate with periods of chemical weathering. The geological dating is hinged on the presence of the two Younger Loesses of the Last Glaciation, and on the fauna of the Mauer Sands (Zeuner, 1944, p. 71), which is slightly more advanced than that of deposits of the Antepenultimate Interglacial, but slightly more primitive than that of the First Preglacial Terrace of Thuringia (at Süssenborn, *l.c.*, p. 262) which is contemporary with the oncoming Elster Glaciation ($ApGl_1$). The most likely age

of the Mauer Sands, therefore, is the interstadial $ApGl_{1/2}$. Soergel (1933), though he agrees that this is their *minimum* age, is inclined to assign greater significance to the gap between (D) and (E), and to push the Mauer Sands back into the Antepenultimate Interglacial. There is no direct evidence for this, and even if it were, Mauer must still be appreciably younger than the Cromer Forest Bed of the same interglacial, on account of the evolutionary stage of the mammalia. *Homo heidelbergensis*, therefore, lived either immediately prior to the first phase of the Antepenultimate Glaciation, or (more probably) during the interstadial of this Glaciation. On the radiation curve, his age would be near 450,000 years.

Achenheim, Alsace (*Clactonian, Acheulian, Levalloisian, Mousterian, Aurignacian*). Of greater typological interest than Mauer is the section of Achenheim, in Alsace, famous since Lyell's days. It has recently been studied with care by Wernert (1929, 1934, 1936). With Mauer as a guide, the climatic succession is easy to follow:

	Deposit	Industry	Climatic Phase
(K)	Recent soil	Neolithic	Postglacial
(J)	Younger Loess II, with cold fauna	—	LGl_2
(I)	Weak weathering soil	Aurignacian	Interstadial $LGl_{1/2}$
(H)	Younger Loess I, with cold fauna	Typical Mousterian (Wernert, 1929)	LGl_1
(G)	Weathering loam	Flakes with unprepared striking platforms, and a small cordiform hand axe	Last Interglacial
(F)	Upper Older Loess, with solifluction at base, and cold fauna	Levalloisian and upper Acheulian	PGl_2
(E)	Weathering loam, slightly decalcified surface of (D)	—	Interstadial $PGl_{1/2}$
(D)	Middle Older Loess. Atypical loess with predominately temperate fauna	Cf. Clactonian (Wernert, 1934, p. 10) or Tayacian (Wernert, 1936, p. 3)	Probably PGl_1
(C)	Weathering loam formed on (B)	—	Penultimate Interglacial
(B_2)	Lower Older Loess	—	$ApGl_2$
(B_1)	Sand-loess and fluviatile sands, with solifluction, and cold fauna	—	$ApGl_2$
(A)	Marls and fluviatile sands of the Rhine, with temperate fauna of the Mauer or Mosbach type (ApIGl)	One early Palaeolithic scraper	Interstadial $ApGl_{1/2}$ or Antepenultimate Interglacial

This section enables us in part to fill the gaps left in the archaeological chronology of the glaciated areas. The Aurignacian appears in the Interstadial $LGl_{1/2}$, i.e. slightly earlier than in Silesia, unless it rested originally *on* the weathering horizon, (I), in a position similar to that at Linsenberg (p. 159), in which case it would more probably date from the beginning of LGl_2. The Mousterian occurs

in the Younger Loess I, i.e. during LGl_1. An unclassified flake industry occurs during the Last Interglacial, and we encounter Levalloisian and upper Acheulian round about PGl_2. Layer (D) suggests PGl_1 as a phase during which an industry with Clactonian technique existed. For the last-named industries, we shall obtain better chronological evidence from northern France and Britain.

Wallertheim, near Mainz (*Mousterian*). That the Mousterian was the industry of the first phase of the Last Glaciation, is confirmed by the interesting site of Wallertheim in the Mainz Basin (fig. 56). Schmidtgen and Wagner (1929) found a Mousterian hunting station on the banks of a small stream, where there appears to have been a watering-place frequented by the larger species of mammals. The occupation horizon is later than the deposition of the main mass of the Younger Loess I, but earlier than the loamy weathering of the interstadial separating the two Younger Loesses ($LGl_{1/2}$). The fauna (Zeuner, 1944, p. 266) consists chiefly of animals of the loess steppe, including the mammoth and the woolly rhinoceros, but several other species indicated that woods had begun to spread. This site, therefore, appears to date from the end of the first phase of the Last Glaciation.

The Younger Loess I, with its weathering horizon, is covered by fresh Younger Loess II. Wallertheim is, incidentally, one of the few places where a third Younger Loess is suggested, a thin loamy band in the 'Younger Loess II' indicating a mild phase which might represent the interstadial $LGl_{2/3}$. If this is so, the upper stratum of the Younger Loess II should, more correctly, be called Younger Loess III. But this does not affect the age of the Mousterian which, here, is found to have survived the climax of LGl_1.

Linsenberg, near Mainz (*Aurignacian*). The chronological position of part of the Aurignacian during the early part of LGl_2 is further confirmed by the site called Linsenberg near Mainz (fig. 57; Schmidtgen, 1930). On the surface of the loamy soil formed on the Younger Loess I, an Aurignacian resting-place was discovered, with a setting of stones and with numerous implements and two sculptures. This site was covered by Younger Loess II. Since the accompanying bones were perfectly fresh, Schmidtgen concluded that no humid weathering took place after they had been left there and that this Aurignacian site dates from the beginning of the cold phase evidenced by the Younger Loess II (LGl_2). It cannot belong to the preceding mild interstadial during which the soil on the Younger Loess I was formed, since in this case the bones would have been destroyed.

Ehringsdorf, near Weimar (*Mousterian*). The earliest Mousterian site which can be placed in the detailed chronology is that of Ehringsdorf near Weimar, in Thuringia (fig. 58). It is famous for its remains of *Homo neanderthalensis*, beside a rich fauna (Zeuner,

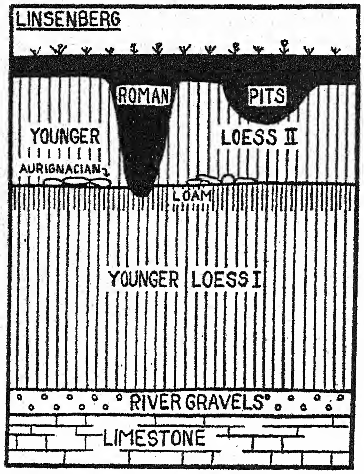


FIG. 57.—Section of the Linsenberg, near Mainz, Rhine Valley, with two Younger Loesses separated by a fossil soil, and an Aurignacian occupation level on the fossil soil.—Based on Schmidtgen (1930), from Zeuner (1944).

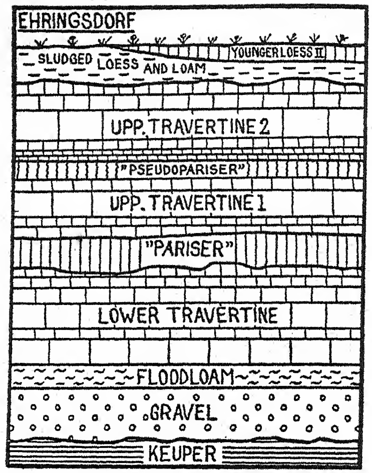


FIG. 58.—Section of the travertines and loesses of Ehringsdorf near Weimar, Thuringia. The Mousterian-Neanderthal occupation level is in the Lower Travertine.—Based on Soergel (1926*a*), from Zeuner (1944).

1944, p. 265) and flora. Occupation layers and fossils occur in deposits of calcareous tufa, or travertine, formed by springs and resting on the fourth glacial aggradation terrace of the river Ilm. The succession has been studied by Soergel (1926*a*, *b*); it is as follows:

(H) Younger Loess II	LGl_2
(G) Upper Travertine, with cool-temperate to temperate fauna	Interstadial $LGl_{1/2}$
(F) Younger Loess I, impregnated with lime from above during the following milder phase. So-called *Pariser*	LGl_1
(E) Lower Travertine, with temperate forest flora, including walnut and *Thuja*, forest mammals, *H. neanderthalensis* and Mousterian industry	Second part of Last Interglacial
(D) Floodloam with mammoth and European pond tortoise	Cool oscillation of Last Interglacial
(C) River gravels of the Fourth Glacial Terrace: cool phase	
(B) Period of erosion	First part of Last Interglacial
(A) Third Glacial Terrace and Saale Glaciation	PGl_2

The dating here given is Soergel's. It relies on the one hand on the presence of two Younger Loesses separated by a mild phase which was not fully interglacial in character, these loesses representing the Last Glaciation, and on the other hand on the interpretation

of the Fourth Glacial Terrace as that of the cool phase which interrupted the Last Interglacial (p. 133), Soergel's *Prewürm* phase.

The Lower Travertine in which the human finds were made, testifies to a very mild climate for the latter part of the Last Interglacial. The average temperature appears to have been somewhat higher than at present. The same is suggested elsewhere, as in the flora of the peat covering the Danish Middle Bed (Zeuner, 1944, p. 33) in the warm mollusca which penetrated into the North Sea at this time (Eem Sea), and in the corresponding warm *Strombus*-fauna which survived into this phase (Late Monastirian) in the Mediterranean. From the archaeological point of view, Ehringsdorf is important because it shows *Homo neanderthalensis*, with a Mousterian industry, living in the warm, second half of the Last Interglacial.

Petersfels near Engen, Lake Constance area (*Magdalenian*). While the loess stations of the Rhine valley, and of upper Silesia, suggest that Aurignacian was present during the episode of climatic decline which culminated in the second phase of the Last Glaciation, other sites have suggested that (apart from some continuation of the upper Aurignacian) Magdalenian had appeared when the retreat of the ice began. This applies both in the Lake Constance area (Kesslerloch, Schweizersbild) and in upper Silesia. The Kesslerloch cave in northern Switzerland further suggested that the Magdalenian persisted through the following interstadial into the third phase of the Last Glaciation (p. 154). This conclusion is strongly supported by the recently excavated cave called Petersfels (Peters, 1930; Peters and Toepfer, 1932; fig. 59). The section of the detrital cone in front of the cave is made up, from top to bottom, of:

(F) Weathering loam, 15 cm.	Postglacial
(E) Coarse solifluction deposit composed of local Jurassic limestone, 40 cm.	LGl_3
(D) Sludge with Magdalenian, 50 cm.	Beginning of LGl_3
(C) Earth with Magdalenian *in situ*, 20–40 cm.	Climate becoming colder
(B) Weathering loam, 15–20 cm.	Interstadial $LGl_{2/3}$
(A) Coarse solifluction deposit of local limestone, 100 or more centimetres	LGl_2

This succession was dated by Toepfer (in Peters and Toepfer, 1932). The two solifluction strata must represent two cold phases. Since the site lies in a glacifluvial valley issuing from the Schaffhausen Moraine (LGl_1), it is likely that the lower solifluction stratum was formed during the following cold phase, that of the Diessenhofen Moraine (LGl_2), and the upper one during the Stein-Singen Phase (LG_3). The great thickness of the lower solifluction, which attains to several metres, indeed suggests that the climate was intensely cold during its formation, though the ice no longer discharged meltwater through the valley. The earliest stage of the Last Glaciation during which such conditions could have prevailed, was

the Diessenhofen Phase. The upper solifluction is thinner, and suggests a somewhat weaker cold phase, such as that of the third phase of the Last Glaciation, locally represented by the Stein-Singen Moraine. None of the later retreat stages of the Last Glaciation has left any stratigraphical evidence in the deposits of the district west and south-west of Lake Constance, so that the dating of the section leads to the same result, whether one starts from the bottom, or from the top.

The Magdalenian deposits with their reindeer fauna were formed when the climate of the interstadial $LGl_{2/3}$ had begun to deteriorate, since chemical weathering evidenced by (B) had ceased, and solifluction apparently started immediately thereafter.

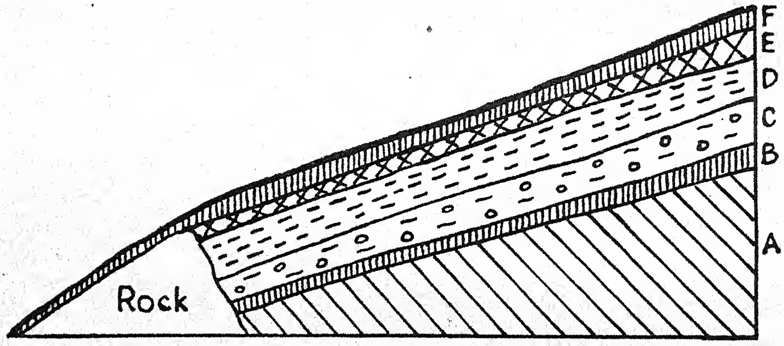


FIG. 59.—Section of the detrital cone of the Petersfels Cave, near Engen, Lake Constance area, after Peters and Toepfer (1932). For lettering compare text. Magdalenian *in situ* in C.

From this evidence and that of the Kesslerloch, it is certain that the Magdalenian survived into the third phase of the Last Glaciation.

Hohler Stein, Westphalia (Mesolithic). The end of the Magdalenian and the beginning of the Mesolithic, after the climax of the Pomeranian Phase (LGl_3) in the Hamburg district were discussed in Chapter IV (p. 72). It may be added that in some Westphalian caves the final Magdalenian is found associated with a mammalian fauna of the tundra type, though a few forest forms are present (Andrée, 1932, 1939). A pre-Tardenoisian with close affinities to the final Magdalenian was found by Andrée (1932) in the Hohler Stein cave, together with abundant reindeer and a few specimens of cave-bear, arctic fox and ptarmigan on the one hand, and wild boar, fox, badger, wild cat, red deer, roe deer on the other. At the time of the early Mesolithic, therefore, the forests had begun to spread, heralding the beginning of the Postglacial.

It is thus probable that the final Magdalenian lasted until the

climax of the third phase of the Last Glaciation was reached, or just passed, and that it gave way to, or developed into, an early Mesolithic before the climate had reverted to a temperate type.

East Europe and Siberia. The archaeological chronology of Europe north of the Alps is summarized in fig. 65 (p. 200). If one ventures farther east, in the hope of extending this chronology, one is thrilled with rich and culturally most intriguing sites discovered in south Russia (Bonč-Osmolowskij, 1935 in Crimea, for instance) and in Siberia (Sosnowsky, 1935).[1] At the same time one is disappointed when, on closer study of the published sections, one discovers that these sites cannot yet be fitted into the detailed climatic chronology. This is so for two reasons.

First, since the modern climate differs more and more from the European one as one goes east, it is unlikely that our system of climatic interpretation of Pleistocene deposits applies farther east. It may still be assumed, with reasonable certainty, that in the whole of south Russia loesses correspond to cold phases and buried soils to interglacials or interstadials; but in central Siberia (Afontowa Gora near Krasnojarsk, or Malta, near Irkutsk), where the recent or interglacial climate is intensely continental, where tjaele occurs as far south as 50° N. lat., and where the reindeer is now found as far south as 49° N., loess and solifluction deposits may well have formed during periods which were not contemporaneous with the glacial phases of Europe. This problem needs investigation before a detailed correlation is attempted.

The second reason why these sites cannot yet be fitted into the detailed chronology is that it has not been possible to work out the local chronology of the Pleistocene. This is, in view of the distances involved and the limitations imposed by the present climate, a most formidable task and we shall probably have to wait for some time before it can be achieved.

Žuravka and Dovginiči, Ukraine (Aurignacian); Derkul (Mousterian). The first area which is likely to produce an archaeological chronology comparable with that of central or west Europe, is southern Russia, where the sequence of loesses has already been worked out and affords an excellent detailed chronology (Krokos, 1927; Zeuner, 1938), especially as the Upper Older Loess was invaded by the extreme southward advance of the Saale Glaciation (Dnjepr Lobe). But the number of Palaeolithic sites which can be dated on local palaeoclimatic evidence is as yet very small. In the loess area of the Ukraine, only one Mousterian site has so far been found (Derkul, a tributary of the Donetz; Mirčink, 1935; Efimenko, 1935), and this in a section which cannot be dated con-

[1] The discoveries made in Russia and Siberia up to 1935 are described Trans. II. Intern. Conf. Assoc. Study Quatern. Europe, Leningrad–Moscow, 1935, fasc. V. For typological review of upper Palaeolithic, see Garrod, 1938.

clusively, though Mirčink suggests that the layer containing the implements was formed 'at the outset' of the Last Glaciation.

As examples of Aurignacian sites in the Younger Loess of the Ukraine, Žuravka (Dept. Pryluka) and Dovginiči (Volhynia) may be mentioned. Both were studied by Krokos (1929, 1930), who found that upper Palaeolithic man lived at these places at the end of the interstadial between the first and second phases of the Last Glaciation, when the mammoth had re-appeared and when the Younger Loess II began to form. This is the same stratigraphical position of the Aurignacian as at the Linsenberg near Mayence (p. 159).

Kiik-Koba, Crimea (*Acheulian*). The lack of Lower Palaeolithic in the loess area of Russia is probably due to the great thickness and wide distribution of the Younger Loess which veils older deposits. In the caves of the Crimea, however, several Lower Palaeolithic stations have been discovered (Bonč-Osmolowskij, 1935). The earliest is Kiik-Koba, where an 'amorphous' industry is followed by 'upper Acheulian' with remains of man. These (only the hand has been studied in detail so far) are regarded as related to Neanderthal Man rather than *Homo sapiens* (Bonč-Osmolowskij, 1941; review by Keith, 1944), a startling find if one considers that elsewhere men resembling *Homo sapiens* appear to have been the makers of the Acheulian industry. Unfortunately, the Acheulian stratum of Kiik-Koba is followed immediately by a surface layer with historical material, so that geological dating is impossible.

It is conceivable, however, that the typological identification of the industries of Kiik-Koba may have to be modified (Zeuner, 1940, p. 14). The 'amorphous' industry appears to have late Clactonian affinities, to judge from the published figures, while the 'upper Acheulian' almost certainly exhibits Levalloisian affinities. The bifaces are mostly made on flakes, and the majority of the 'hand-axes' are worked on one side only. If this industry turns out to be a late Levalloisian, or a Levalloiso-Mousterian, the difficulty of having Neanderthal man associated with Acheulian would be removed. Further notes on this interesting site will be found in Bonč-Osmolowskij's monograph, in Boule (1925, 1926), and Gromova and Gromov, 1937.

Upper Palaeolithic of Siberia. It has been pointed out above that the correlation of the Siberian Palaeolithic with that of Europe is still a matter of controversy. It also is a matter of importance, however, since here we encounter in one and the same industry a combination of Mousterian, upper Palaeolithic and even Mesolithic traits which, in Europe, are successive and spread at least from the end of LGl_1 to the end of LGl_3. The material has been ably summarized and discussed by Sosnowskij (1935).

Malta, near Irkutsk. The earliest stations are Malta, Irkutsk

(Military Hospital), and Kaiskaja Gora, all three in the area of Irkutsk on the Angara River, north of Lake Baikal. Their fauna is predominately arctic and includes the mammoth and the woolly rhinoceros, and their industry is essentially based on mammoth ivory, bone and antlers. Typologically, the industry has been compared with the Aurignacian and Solutrian of Europe by Salmony and Gerassimow, and by Gromov with the late Magdalenian. Consulting the stratigraphical position as a possible clue to correlation, we find that the sites occur in a loess-like deposit resting on fluviatile loam and gravel of a terrace 18 metres above the river. They are, therefore, later than the fluviatile phase of the aggradation of this terrace, but earlier than the deposition of the main mass of the loess.

The formation of this terrace is, however, followed by (1) a period of down-cutting, (2) the accumulation of a 9 to 12-metre terrace, (3) a further down-cutting, and (4) the establishment of the present river level with its floodplain. This is a considerable sequence of events which makes it difficult to interpret the term 'end of Würm' used for the age of Malta as meaning the end of LGl_3, which it would have in Europe. Since no attempt has apparently been made to study the terrace system from the climatic point of view, or its relation to the sea-level, it is impossible to arrive at a clear view of the age of these stations.

Afontova, near Krasnojarsk. The same applies to the later stations, many of which are concentrated in the Krasnojarsk area on the Jenisei river (for instance, Afontova II, lower horizon; Korokewo II, etc.), which were occupied partly during a later phase of loess formation, and partly when the down-cutting had begun.

A still later group of stations (Gromov's Group II) dates from the phase of down-cutting following the aggradation of the 9 to 12-metre terrace at Krasnojarsk. By this time, the mammoth and the woolly rhinoceros had disappeared, and reindeer, horse and aurox characterize the fauna. This group comprises the sites called Sabočki near Korokewo, and 'Immigrants' Point' near Krasnojarsk.

Finally, a last group (Gromov's Group III) occurs in various deposits, apparently always near the surface (Afontova II, upper horizon; Afontova IV, Gremjačij stream, near Krasnojarsk). In these, bone artefacts have become rare, and many microlithic implements are present.

The last two groups are classified as 'Postglacial' by the Russian authors. But the long sequence of geological events beginning with the formation of the 18-metre terrace, regarded as 'final Würm', makes one suspect that these terms, as applied to the Siberian Palaeolithic, must not be interpreted in the light of the climatic chronology of Europe. Even though one has to leave open the question what climatic conditions are indicated by river erosion and river aggradation in Siberia, it is clear that during the period

covered by the Siberian Palaeolithic, the rivers have passed through two complete cycles of aggradation and erosion, involving some 50 feet of lowering of the river's course in a flat country. It is difficult to conceive of all this having happened since LGl_3, say within 15,000 years. The evidence for two cycles of accumulation and erosion suggests rather that the earliest sites (Malta, &c.) are about as old as LGl_2, whilst the latest could well be as late as near the end of LGl_3, or the beginning of the Postglacial. It will be interesting to watch the outcome of further stratigraphical work in Siberia. Let us hope that our Russian colleagues will find it possible to make the river terraces and the phases of loess formation the subject of a special study.

C. PALAEOLITHIC OF FRANCE, CHANNEL ISLANDS AND PORTUGAL

France is the classic region of prehistory, especially of the Palaeolithic. Of all countries, France has supplied us with the most complete succession of Palaeolithic industries, and the French typological divisions have become the standard for the world. As regards the detailed chronology of the Pleistocene, however, the only part of France where geological evidence is sufficiently ample, and has been investigated from this point of view, is the valley of the Somme in northern France. This important work was begun by Commont, and continued by Breuil. The connexion of the fluviatile terraces with the ancient beaches on the coast of the English Channel has been elucidated by de Lamothe. The enormous archaeological wealth of the Somme valley and the practical necessity to classify all the important sites within a working chronological system, has tended to obscure the eyes of students to the fact that the number of sections which are conclusive from the point of view of climatic chronology are not many. A few from this number have been selected here for the purpose of demonstrating the detailed chronology of the Palaeolithic of the Somme valley.

Somme Valley. The loesses of the Somme valley (pl. XII, fig. B) are similar to those observed in the Rhine valley, with the difference that the Younger Loess is less thick; the Younger Loess II apparently being somewhat under-developed. This is in agreement with the westerly situation of the Somme, where the climate is likely to have been influenced by the sea more during LGl_2 than during LGl_1, in accordance with the smaller size of the ice-sheet.[1] Conversely, solifluction deposits are more conspicuous in the Somme than they are farther east, for the same reason.[2]

[1] Breuil has recently subdivided the two Younger Loesses into two each, but there is no evidence from buried soils that this further subdivision corresponds to separate glacial phases. No more than two, therefore, are distinguished here, in accordance with the conditions observed in most parts of temperate Europe and in accordance with Breuil's system prior to 1936.

[2] For further discussion of these points, see Zeuner (1944, p. 80).

The fluviatile terraces of the Somme (pl. XII, fig. C) are, unfortunately, of that complex type prevailing in rivers above the estuary. The movements of the sea-level have combined with climatic aggradation and erosion in a most complicated manner, and great tribute has to be paid to H. Breuil's intuition that has led him to date the industrial sequence so correctly (Breuil, 1932, 1937, 1939). It is impossible in the present context to proceed on strictly logical lines by building up, from various sections, the complete detailed chronology and to prove that only this chronology satisfies the evidence. This has been done in another place (Zeuner, 1944, p. 81 ff.). The sections given, however, do provide some idea of the geological evidence available.

Porte du Bois, Abbeville (Abbevillian). Abbeville lies not far from the neck of the modern estuary of the Somme. The pits of the Porte du Bois, just outside the town, have been famous for many years. One of them, the carrière du Moulin-Quignon, is the veritable birth-place of the Palaeolithic, since it was from here that Boucher de Perthes, in 1847[1], described for the first time human implements associated with extinct mammalia. Chronologically more important is the carrière Carpentier, from which d'Ault du Mesnil (1896) made known a rich Abbevillian[2] industry associated with a mammalian fauna of the age of the Cromer Forest Bed. On palaeontological evidence alone, therefore, this deposit proves to be Antepenultimate Interglacial.

Commont (1910*f*) was unable to confirm d'Ault's discoveries, but Breuil (1939*a*) has, by means of fresh excavations and a careful scrutiny of the published evidence, proved convincingly that there is no reason to doubt d'Ault's claim.

The section of the carrière Carpentier (Commont, 1910*f*; Breuil and Koslowski, 1931) may be summarized as follows:

(VIII) Top layer, possibly containing some Younger Loess.

(VII) Older Loess, weathered to argile rouge.

(VI) *Cailloutis* (pebble layer) covering the sands of (V), with lower Acheulian implements (Acheulian II) apparently derived from the underlying sands.

(V) Upper Gravels and Sands, with two rolled, and therefore derived, Abbevillian hand-axes, beside a 'beautiful Acheulian I, which is fresh and well-worked' (Breuil, 1939*a*, p. 30). Fauna with typical *Elephas antiquus*, of middle Pleistocene type. Altimetrically, the surface of this fluviatile aggradation runs into the Tyrrhenian

[1] Boucher de Perthes (1849). See also his answer to the Laon archaeologists (1859), which gives a vivid picture of the suspicion by which Boucher's claims were met and of his firm conviction that his observations were correct.—Rigollot (1855) reported the discovery of the first implements at St. Acheul.

[2] Commont's Pre-Chellian = Chellian of many authors was renamed Abbevillian by Breuil; see Breuil (1939*b*). Commont's Chellian = lower Acheulian of Breuil. Note this when reading Commont's papers.

(32 metres) sea-level of the Penultimate Interglacial. We may conclude, therefore, that early Acheulian man lived while the sea rose to its maximum level during this Interglacial.

(IV) Sharp erosional unconformity. Commont observed a small bed of peat. An erosional phase during which the river cut to a low sea-level.

(III) White Marl, with sandy layers and with an Abbevillian industry. Fauna composed of early Pleistocene species and ' Pliocene survivals ', like *Elephas meridionalis*, *Equus stenonis*, *Trogontherium*, typical of the Antepenultimate Interglacial.

(II) Sand with shells.

(I) River gravel with *Hippopotamus* and *Equus stenonis*, referable to the same interglacial as (III).

The sections from Abbeville thus suggest that the Abbevillian belongs to the Antepenultimate, and the lower Acheulian to the Penultimate, Interglacial.

Amiens, carrière Fréville (*Abbevillian, Clactonian, Acheulian, Levalloisian*). Twenty-five miles upstream from Abbeville, as the crow flies, we meet with the second important group of sections in the neighbourhood of Amiens, especially in the suburb of St. Acheul. The carrière Fréville at St. Acheul is important because it confirms the results obtained at Abbeville and permits us to link them up with the sequence of the carrière Bultel-Tellier. The section consists of:

(VII) Weathered surface of Younger Loess.

(VI) Younger Loess. At its base (presumably from the time of the preceding interglacial (LIgl), middle Levalloisian (Lev. III–IV of Breuil).

(V) Argile rouge, weathered surface of Older Loess. With patinated upper Acheulian (Acheulian V). Weathering of Last Interglacial.

(IV) Older Loess. No implements in the loess, but early Acheulian incorporated in the cailloutis at its base, the produce of denudation previous to the commencement of loess formation.

(III) White sand with lenses of gravel. In the sands, Acheulian I, and numerous implements of Acheulian II on their surface. Interglacial aggradation of the river. Penultimate Interglacial.

(II) Weathering, and period of denudation. Gap in the geological record.

(I) Lower Gravels, in the Rue du Comte-Raoul with primitive *Elephas antiquus* as found at Abbeville, indicating Antepenultimate Interglacial. At carrière Fréville with atypical implements only, but in the neighbouring carrière Leclercq with numerous Abbevillian and Clactonian specimens.

This succession agrees with that from Abbeville in the superposition of a river deposit of the Penultimate Interglacial, with lower Acheulian

(layer III at Fréville, V at Abbeville), on a river deposit of the Antepenultimate Interglacial, with Abbevillian and Clactonian (layer I at Fréville-Leclercq, I–III at Abbeville). These sections tell us that the Abbevillian was the hand-axe culture of the Antepenultimate Interglacial, while the Acheulian appeared during the Penultimate Interglacial. The view held in Germany for many years that the Abbevillian belongs to the Penultimate Interglacial and which is still defended by Andrée (1939), therefore, is no longer tenable. This author's suggestion that something appeared to be wrong in the French succession because he arrived at a different result, falls to the ground, since the geological evidence for the age of the Abbevillian in northern France is sound. It is possible that what Andrée calls 'Chellian' at Neanderthal (his test site) is, in the modern French classification, early Acheulian.

St. Acheul, carrière Bultel-Tellier (*Abbevillian, Clactonian, Acheulian, Levalloisian, upper Palaeolithic*). The sections of the carrières Bultel and Tellier at St. Acheul are perhaps the most important in Europe for the chronology of the lower Palaeolithic, since they give us dates for several industries within the detailed chronology. They were studied extensively by Commont (many papers between 1909 and 1913, especially 1909*c*). The more recent paper by Breuil and Koslowski (1931, p. 471) contains a synthesis of Commont's earlier work, as well as of their own. The section has been discussed in Zeuner (1944, p. 86) from the view-point of climatic chronology, so that we can confine ourselves to a summary providing chiefly the archaeological evidence (fig. 60):

(XI) Re-deposited Younger Loess (probably result of ploughing), with Neolithic.

(X) Postglacial weathering of Younger Loess II.

(IX) Younger Loess II, in its upper, weathered portion with upper Aurignacian and Solutrian. At its base, in a cailloutis possibly comprising remnants from the preceding interstadial, Levalloisian VI. LGl_2.

(VIII) Weathering of Younger Loess I. Interstadial $LGl_{1/2}$.

(VII) Younger Loess I, with a cailloutis in the middle, containing upper Levalloisian (Lev. V). At the base, another cailloutis, also with Levalloisian V.[1] LGl_1.

(VI) Argile rouge, weathering of the Older Loess. In its upper portion, upper Acheulian (Acheulian VI–VII, Micoquian) has been found. Some of the implements lay, with one of their faces, in the argile rouge, and with the other in the cailloutis layer at the base of the Younger Loess (Commont, 1909*c*). They are patinated white, which testifies to the intense weathering they suffered. This

[1] In the explanation of fig. 10 in Breuil and Koslowski, 1931, p. 472, it is called Lev. III–IV instead. This possibly refers to certain specimens found by Commont on the surface of the argile rouge.

industry, therefore, at least in part belongs to the prolonged mild period which followed the deposition of the Older Loess and preceded that of the Younger Loess, i.e. the Last Interglacial.

(V) Older Loess. No implements in the unweathered portion. PGl_2.

(IV) Red sands (*Sable roux* of Commont, Breuil, &c.), resting on eroded surface of earlier deposits (except where III is present). This appears to be a hill-wash formed during the initial stage of PGl_2.

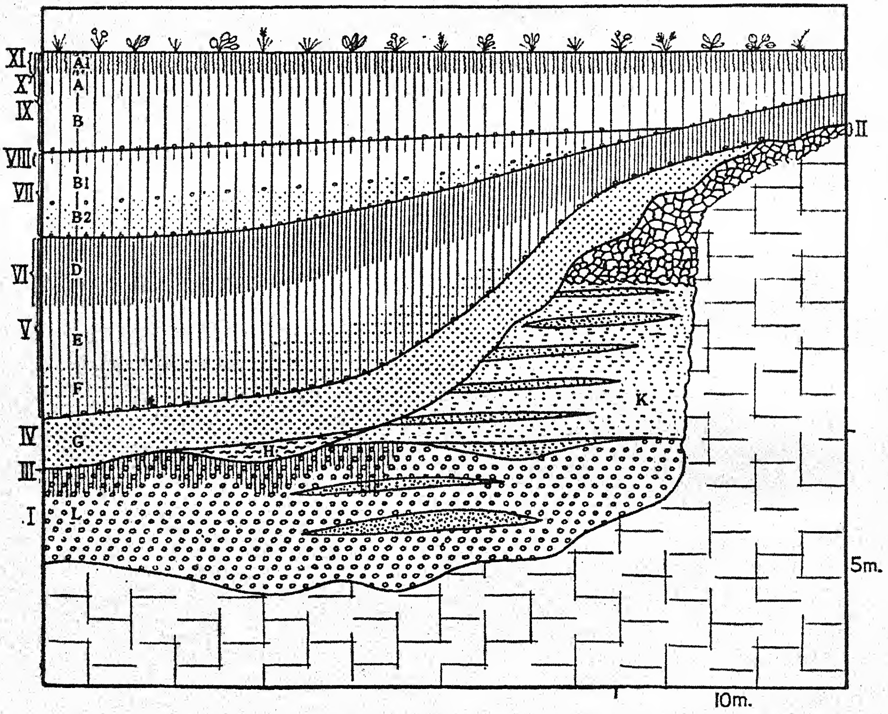


FIG. 60.—Section of the Carrières Bultel-Tellier, Saint-Acheul, near Amiens, north France. For explanation, see text, p. 169.—After Commont (1909*c*, 1912) and Breuil and Koslowski (1931), from Zeuner (1944).

At the very base of the red sands, a middle Acheulian site was found (Acheulian III, Breuil, 1931 ; Acheulian III*b*, Kelley, 1937 ; Acheulian IV, Breuil, 1939*b*). It is known as the *Atelier Commont.* The implements are strongly patinated, whilst others occurring at a higher level in the red sands are not. It is likely, therefore, that they were subjected to weathering before the red sands were deposited, and that they belong to some phase earlier than that of the red sands. On the other hand, the Atelier cannot be older than the fluviatile series (I, below) on which it rests. This middle Acheulian,

therefore, dates from the Penultimate Interglacial at the earliest, and at the latest from the interstadial $PGl_{1/2}$.

While the climate deteriorated and the red sands were deposited, middle Acheulian man once more appeared on the scene: a second middle Acheulian horizon (Acheulian IV, Breuil) is found *in* the red sands.

(III) Lens of white chalky sand, local. Where present, resting on the eroded surface of (I). According to Breuil and Koslowski, the shell fauna suggests a 'moderately warm' climate. Interstadial $PGl_{1/2}$.

(—) An erosional unconformity separates the earlier deposits from the later (fig. 60).

(II) *Coombe-rock* (frost-weathering debris consisting of chalk), correctly interpreted by Breuil and Koslowski as formed under cold conditions. PGl_1.

(I) Fluviatile gravels below and fluviatile sands above, of the aggradation leading to the Tyrrhenian sea-level. Penultimate Interglacial, confirmed by fauna.

The gravels contain derived Abbevillian and an un-rolled Clactonian industry which was found *in situ* by Breuil. The sands have yielded an early Acheulian (Acheulian II).

A weathering which affected the gravels is shown both by Commont and Breuil and Koslowski as passing *underneath* the sands. This 'weathering'[1] might afford a parallel to the weathering of the Lower Loam in the 100-foot Terrace of the Thames at Swanscombe, with Clactonian underneath the weathering horizon, and Acheulian above. These two sections assign to the 'Clactonian II' an early part of the Penultimate Interglacial, and to the Acheulian a later one. It must not be overlooked, however, that while the date for Clactonian II appears to apply generally, the Acheulian may well be partly contemporary with it. In Swanscombe, early middle Acheulian is found above the weathering horizon, in St. Acheul, the specimens have been classified as lower Acheulian.

This section thus provides us with a wealth of chronological information. On its evidence, we may assign—

The Abbevillian to a time prior to PIgl.

The Clactonian II to an early part of PIgl.

The lower Acheulian (Ach. II) to some later part of PIgl.

The middle Acheulian (Ach. III/IV) to from late PIgl to early PGl_2.[2]

The upper Acheulian (Ach. VI–VII, Micoquian) to LIgl.

[1] Provided it *is* a true weathering horizon.

[2] The uncertain position of the Atelier Commont makes it difficult to state the beginning of the middle Acheulian at St. Acheul, but Kelley (1937, p. 18) found Acheulian III*a* in the neighbouring site of the 30 metre-terrace gravels at Cagny. This establishes the presence of early middle Acheulian in the Penultimate Interglacial of the Somme.

The Levalloisian V to end of LIgl and LGl_1.

The Levalloisian VI to interstadial $LGl_{1/2}$ or early LGl_2.

The upper Aurignacian and Solutrian to climax of LGl_2.

It will be noticed that the evidence from other sites in France and farther east tallies well with this succession, except in the survival of the Levalloisian into $LGl_{1/2}$ or even LGl_2. By this time, Aurignacian appears to have been present in some parts of Europe. The difference, however, is slight, since when the second phase of the Last Glaciation reached its climax the upper Palaeolithic had arrived at St. Acheul also, with the same industries as are found elsewhere at this time. It will be interesting to see whether this apparent survival of the Levalloisian is a matter of some significance or not. For this purpose we have to turn to the Seine valley.

St. Pierre near Rouen, survival of Levalloisian into upper Palaeolithic times. The sections in the brickearth pits of St. Pierre-les-Elbeuf, not far from Rouen, on the slope of the Seine valley, present evidence for two Younger Loesses separated by a horizon of humid weathering, resting on thick Older Loess which is weathered to argile rouge in its upper portion. This is the succession with which we are now familiar of PGl_2 (Older Loess), LIgl (argile rouge weathering), LGl_1 (Younger Loess I), $LGl_{1/2}$ (weathering), and LGl_2 (Younger Loess II). Contrary to expectation, the sections have not provided evidence for a greater number of loesses, even after a detailed examination of the buried soils and mechanical analysis of numerous samples (Zeuner, 1944, p. 81).

Special interest is attached to St. Pierre by the Palaelothic implements it contains. I am grateful to Mr. Harper Kelley, of Paris, for the information he gave me on this matter and for his permission to mention the finds, which are preserved in the Laboratoire de Préhistoire of the Muséum d'Histoire Naturelle in Paris. The archaeological significance of this site has previously been stressed (Leakey, 1934, p. 134).

In the lower pit (briquetterie Bigot), upper Levalloisian (Lev. VI–VII) occurs at the base of the Younger Loess II and in its lowermost twelve inches. The same lower Palaeolithic industry is found towards the top of the soil on the Younger Loess I. It will be remembered that, in central and east Europe, Aurignacian appears in this stratigraphical position, but the upper Levalloisian has been found in this level at St. Acheul and, according to Breuil and Kelley, it is quite frequent in the cailloutis at the base of the second Younger Loess of northern France. If it can be shown, therefore, that this Levalloisian occurs *in situ*, in particular in the lowermost twelve inches of the Younger Loess II at St. Pierre, we should have clear evidence for the survival of the upper Levalloisian into the second phase of the Last Glaciation, i.e. into a period when the Aurignacian had established itself elsewhere in Europe.

Outside the present working portion of Bigot's pit, towards the upper pit, called Grande Briquetterie, some implements of upper Palaeolithic aspect have been found. Mr. Kelley collected from the floor of the excavation three cores, two burins, two backed blades and one scraper, and the workmen claim to have obtained from the *surface of the Younger Loess I* two cores and one blade.[1] This material would, in central or east Europe, be in its correct stratigraphical position, but here it conflicts with the evidence of Bigot's pit and many other places. So far as the evidence goes at present, and provided that the stratigraphical positions of the implements are confirmed by further finds, it is suggested that upper Palaeolithic man penetrated to the Seine for a short time at the end of the interstadial between the first and second phases of the Last Glaciation, whilst the lower Palaeolithic continued in spite of this invasion, into the early part of the second phase of the Last Glaciation. This survival was not a general phenomenon. We have met it here in northern France for the first time; and we shall find it suggested in other parts of Europe also (p. 288). It is a highly interesting phenomenon, and it is desirable that special attention be paid to sections covering the critical period, with the view to dating as closely as possible the succession of industries.

The briquetterie Bigot has further yielded implements which help to continue the Palaeolithic sequence into the past. From the *base* of the Younger Loess I, a Micoquian handaxe was recovered, whilst a handaxe of the type of Levalloisian V came from the top of the argile rouge. These industries, therefore, would date from the time before the beginning of the deposition of the Younger Loess, or at the latest just from its beginning. This agrees with their position in St. Acheul and other parts of France.

Renancourt near Amiens (middle Aurignacian). By the time of the climax of LGl_2, the Aurignacian was established in northern France. This is borne out in St. Acheul and in other sections of the Somme valley.

No lower Aurignacian (Chatelperronian of Garrod, 1938) appears to be known, but middle Aurignacian (typical Aurignacian) has been recorded by Commont (1913*a*, p. 504) from Renancourt near Amiens. The section (Commont, 1911*b*, p. 241) is as follows:

(IV) 'Hill-wash' of loessic material.

(III) Upper loess-loam, together with (IV), 1·5 metres.

(II) Younger Loess, 2·5 metres.

(I) Cailloutis, with middle Aurignacian.

(—) More Younger Loess (Commont, 1913*a*, p. 504), 2·7 metres or more (Commont, 1913*b*).

[1] A Levalloisian flake, however, was extracted in my presence from the weathering horizon of the Younger Loess I.

Commont states that this industry occurs in the latest loess at a depth of about 2 metres.[1]

Montières near Amiens, Basse Terrace (*upper Aurignacian*). The position of the upper Aurignacian (see also St. Acheul) is stated to be in the 'partie supérieure de l'ergeron (löss récent) ou limon de débordement le couronnant sur les rives actuelles (basse terrasse)' (Commont, 1913*a*, p. 504). At Montières, for instance, it occurs in a whitish silt immediately above the Younger Loess, considered as a fluviatile deposit by Commont, *below* a deposit containing his pre-Solutrian to be discussed presently. It is very difficult to interpret these late Pleistocene silts of the Low Terrace and the floodplain of the Somme. Breuil and Koslowski (1931), too, have paid attention to this problem and have succeeded in proving in some cases their fluviatile origin, whilst in others they have been able to identify some of Commont's *limons* with Younger Loess. But from published sections which can no longer be checked in the field, it is impossible to deduce the origin of this type of deposit.

Belloy-sur-Somme (*pre-Solutrian*). An upper Palaeolithic with Solutrian affinities, called pre-Solutrian by Commont, was found at Belloy-sur-Somme (Commont, 1909*b*, 1910*d*; Breuil and Koslowski, 1931, p. 310, with further references). The level of this industry is at the top of the fresh Younger Loess at the base of the loamy soil (terre à briques). Commont (1910*d*, p. 801) was aware that this industry belongs to the final phase of loess formation. Typologically he compares it with the pre-Solutrian horizon below the true Solutrian at Solutré, but there are strong affinities to the upper Aurignacian also.

Solutrian and Magdalenian of the Somme valley. The Solutrian is found on the surface of the Younger Loess; Commont (1913*a*, p. 504) mentions Conty as a locality where it was found in a section, covered by hill-wash containing Neolithic and Gallo-Roman remains.

The Magdalenian, too, is restricted to the surface of the loess, though it is often covered by peat and hill-wash filling the buried channel of the Somme.

Commont has repeatedly emphasized that the succession of the upper Palaeolithic of the Somme represents a very short space of time. This is borne out by the sections. We have found belated Levalloisian in the lowermost Younger Loess II, in its middle, Middle Aurignacian, in its upper portion upper Aurignacian and pre-Solutrian, Solutrian at or very near the surface, and Magdalenian on the surface. This is the same rapid succession of upper Palaeolithic industries that has been found elsewhere in the Younger Loess II,

[1] Conflicting statements concerning the industry are found in Commont (1913*b*). On p. 578, it is called 'nettement Aurignacien typique (Aurignacien moyen . . . de la Dordogne)'. On p. 573, it is called 'Aurignacien supérieur'. It is also recorded from the loess-loam, not from the cailloutis. Possibly there are two horizons, but Commont speaks of only one.

with the difference that (the Aurignacian having put in a precocious appearance at St. Pierre during the Interstadial $LGl_{1/2}$), the final Levalloisian survived into this phase (LGl_2), and that the Magdalenian has so far been found on the surface only. This, however, need not mean a real retardation of this industry, since loess formation must have ceased almost immediately after the climax of a glacial phase, especially in a country so far west as northern France, where the influence of the ocean was stronger than farther east. On the other hand, some of the Magdalenian of northern France may be rather later, but the complete absence, up to the present, of deposits of LGl_3 renders exact dating impossible.

Thus, except for the survival of the final Levalloisian, the Palaeolithic succession of northern France agrees chronologically with that of the Rhine and farther east.[1]

The French succession is tabulated in fig. 65, p. 200.

Jersey, Channel Islands. The subdivision of the Last Interglacial by a cool phase which has been encountered in central Europe is not evident in the French rivers, except for the distinction of a High Low Terrace and a Low Low Terrace introduced by Breuil and Koslowski (1932, p. 27). But this still does not help in the dating of industries within the Last Interglacial. Since the two warm parts of the Last Interglacial have left the clearest evidence in the two Monastirian beaches, it is worth while to study an area where these beaches are preserved. Jersey, the largest of the Channel Islands, affords good opportunities (Mourant, 1933, 1935).

Cotte à la Chèvre (*Levalloisian*). Three beach levels have been identified in Jersey, one at 33 metres (Tyrrhenian), one at 18 metres (Main Monastirian; Pl. XIV, fig. B; XV, fig. A), and one at 7·5 metres (Late Monastirian; pl. XIV, fig. A; XV, figs. A, B). The Tyrrhenian beach contains no implements. There is, however, an interesting occupation site on the 60 feet (Main Monastirian) level, the Cotte à la Chèvre (fig. 61; pl. XIV, fig. B).

When investigating the cave in 1938, I obtained an untouched section close to the east wall. Earlier excavations (Sinel, 1912, 1923; Marett, 1911) have disturbed most of the deposit, since the presence of huge boulders prevented the digging of proper trenches. The section is reconstructed in fig. 61. Whilst the view has been held that the lower part of the implementiferous layer (3) was sterile, it is now established that the worked flints occur throughout this layer in a peculiar manner. The layer is interrupted by large boulders, some measuring several feet, which rest in the underlying beach sand and pierce the whole section. The grey horizon (3) con-

[1] The form of this statement is necessitated by our chronological approach. From the typological point of view, France should be regarded as the standard region, and tribute be paid to the French workers who have been able to disentangle the industrial succession often without the conception of a detailed climatic chronology.

tains flints right down to the surface of the beach sand which itself is sterile. Flint chips are especially numerous near some of the large boulders, and many were found in a vertical position in the gaps between the boulders. One boulder stood on its narrow edge. This

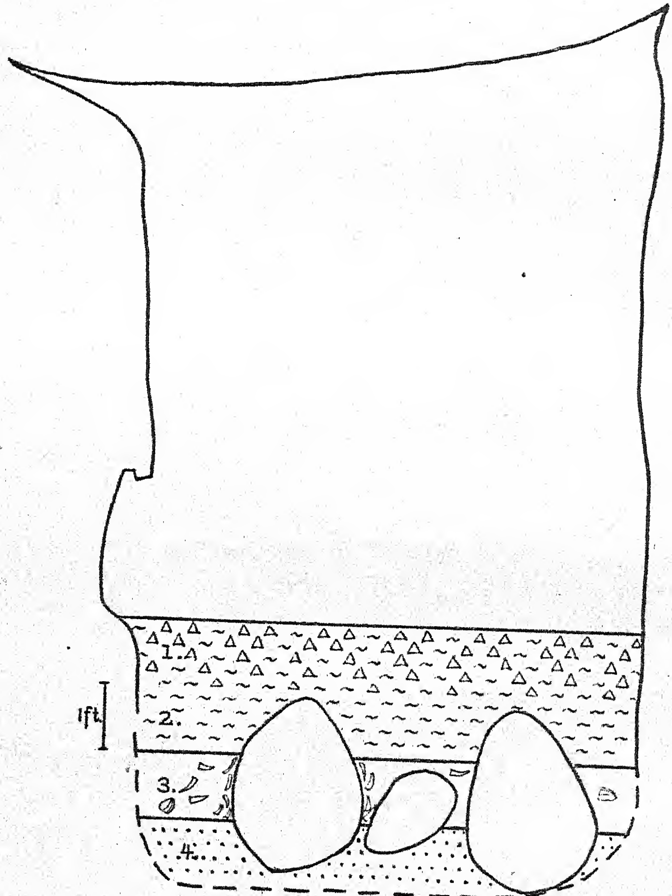


FIG. 61.—Section of the Cotte à la Chèvre, Jersey, Channel Islands. (1) Loess mixed with granitic grit. (2) Purer loess. (3) Whitish-grey clay with numerous flint flakes, especially near the boulders. (4) Bed of beach sand, with huge boulders penetrating the higher horizons.—Based on records, diagrams, and new excavations.

shows that (*a*) the boulders were used as anvils and that the cave was a workshop, and (*b*) that the occupation began when the beach sand (4) and the boulders were the only deposits. The grey clayey layer (3) was formed during the occupation. The obvious conclusion to be drawn is that the occupation of the site followed the formation

of the beach *without* a long interval. Typologically, the implements are middle to upper Levalloisian.

The top of layer (3) is stained brown, and probably weathered.

The higher part of the section is made up of a loess-like loam which, in its upper portion, contains granitic grit. Petrologically the gritty portion resembles the head found elsewhere in the island. According to Sinel, it contained flint flakes, but unfortunately vestiges only of the deposit are now left, and the statement cannot be checked.

The importance of the Cotte à la Chèvre lies in the evidence it affords for the following sequence of events:

(*a*) Formation of the deposits of the 60 foot shore-line.
(*b*) Recession of the sea, very soon followed by
(*c*) occupation by middle or upper Levalloisian man.
(*d*) Weathering of the occupation layer under a temperate climate, followed by
(*e*) deposition of loess and head under cold conditions.

There cannot be any gap worth speaking of between the beach deposit and the occupation. On the other hand, the phase of occupation was followed by a period of weathering indicating prolonged interglacial conditions. Since, altimetrically, the beach deposit belongs to the Main Monastirian phase, the middle or upper Levalloisian of this site has to be assigned to the earlier half of the Last Interglacial.

Cotte de St. Brelade (*Levalloisian*). The cave called Cotte de St. Brelade has become known for the discovery of thirteen isolated teeth of *Homo neanderthalensis* (Keith and Knowles, 1912). This site has been patiently excavated by Dr. R. R. Marett for many years (1911, 1916). Thanks to his great kindness I was enabled in 1938 to study the site and to carry out some excavations in order to try and find geological evidence for the age. My results have been recorded elsewhere in detail (Zeuner, 1940, pp. 10–13), so that it suffices here to give a short summary. Contrary to the widely held view that the deposits of this cave rest on the Main Monastirian beach, no beach deposits were found. If there is one at all, it must be below 50 feet O.D. It is likely that this fissure cave is older than the Monastirian, since it contains a loess which, being covered by interglacial deposits, has to be regarded as an Older Loess, and not younger than the Penultimate Glaciation. The overlying interglacial beds of clay and sand have yielded a temperate flora and fauna, including *Elephas* cf. *antiquus* and a Middle Levalloisian industry. They are covered by a Younger Loess, with hearth levels, remains of Neanderthal man, a late Levalloisian industry (VI–VII) and a cold fauna. No further subdivisions can be made, but it is difficult to interpret this section otherwise than by regarding the Younger Loess as that of the first phase of the Last Glaciation,

and the interglacial deposits as those of the Last Interglacial. The Cotte de St. Brelade, therefore, does not provide information about the relation of the industries to the sea-levels, but it tells us that during some time of the Last Interglacial, middle Levalloisian man lived in Jersey (confirming Cotte à la Chèvre), and that *Homo neanderthalensis*, with a final Levalloisian, lived during the loess phase of the LGl_1. This association of Levalloisian with Neanderthal Man, always assumed to be correct, is known as a fact from this site only, except for the Levalloiso-Mousterian of the Tabun cave at Mount Carmel, Palestine.

Flint implements in 25 foot-shore-line of Jersey. Flint implements have further been found in sections comprising the 25 foot-beach (Late Monastirian). At Belcroute Bay, flakes were found *in situ* at the base of the head lying on the pebble bed, by Mourant and Mrs. Hawkes (1939), and an almost unworn hand-axe, presumably derived from the same horizon, lay on the Recent beach. Another, more interesting set comes from Petit Portelet, the north side of the neck connecting Mont Orgueil (Gorey Castle) with the main island. A shingle deposit rests on the platform of the 25 foot-beach and is covered by head and loess-like loam. About 10 specimens with a white patina have been recovered and are preserved in the Museum of the Société Jersiaise, and Dr. Mourant kindly informed me that some were found *in situ* in the upper part of the section. The patina is indeed that of specimens embedded in loess. Some, however, are in a rolled condition and must have been picked up on the modern beach. Four of the specimens are interesting from the typological point of view. One of them (coll. Watson) is almost a blade. It is about 8·5 cm. long and 2–3 cm. wide and of a triangular cross-section. The platform is flat, and its angle 90°. One edge is retouched. This specimen could be upper Palaeolithic, or older. A second specimen (coll. Watson) is a thin flake, 7 cm. long and 8·5 cm. wide. It is chipped so as to form a broad oval. Its bulb end is very thin, and one surface is covered with scars suggesting that it was struck from a carefully prepared core.

Two further specimens (coll. Lawson), both about 3·5 cm. wide, and respectively 5 and 6·5 cm. long, are worn, but at least one of them shows a prepared striking platform. The last three specimens mentioned suggest that the industry is Levalloisian (or possibly Mousterian), and certainly not upper Palaeolithic. The middle Palaeolithic thus proves to have survived the Late Monastirian shore-line in Jersey as elsewhere.

Portugal, Palaeolithic on Pleistocene beaches. The distribution of Palaeolithic industries over the successive phases of Pleistocene sea-level has quite recently been studied in Portugal (Breuill, Vaultier and Zbyszewski, 1942; Zbyszewski, 1943) and in Morocco (Neuville and Rühlmann, 1941). The latter work has not yet been available

to me. These investigations have extended the chronology along the Atlantic sea-board down to West Africa. It is to be hoped that further work of this kind will eventually result in a linking up with the great and important Palaeolithic province of South Africa.

For Portugal, Zbyszewski's interesting treatise, the result of over two years collaboration with H. Breuil, suggests evidence for a succession of sea-levels and industries which agrees in all major features with that found in the remainder of Europe:

(I) Sicilian beach (80–100 metres). First Abbevillian, rolled.

(II) Milazzian beach (45–65 metres), and corresponding thalassostatic river terraces. The latter with rolled Abbevillian and Clactonian.

(III) Tyrrhenian beach (20–40 metres). Rolled early Acheulian in the beach deposits, middle and upper Acheulian in the overlying red sands. In the corresponding river terraces, middle Acheulian.

(IV) Monastirian beaches (called *Grimaldian*; not subdivided, but apparently mostly Late Monastirian, since generally below 12 metres). With Languedocian[1] *in situ*. In corresponding river terrace, Mousterian.

The complete chronology of Zbyszewski is much more ambitious than the skeleton here given; it includes the phases of regression between the high sea-levels also. It must be kept in mind, however, that the altimetric levels of the beaches have not yet been studied in detail, that many sites are *on* the beaches, or in superimposed non-marine deposits, which need not have been formed immediately following the beach formation and may be much later. But from the wealth of material considered by Zbyszewski it is already evident that Portugal offers an opportunity of developing a detailed chronology of the Pleistocene sea-levels, as the back-bone of a detailed chronology of the Palaeolithic. As it stands, Zbyszewski's present scheme is extremely reasonable, though the dating of the sites appears in some instances to have been based on archaeology rather than on geology. (See Note (4), p. 388.)

Palaeolithic of Moroccan beaches. In Morocco (Neuville and Rühlmann, 1941, quoted from Zbyszewski, 1943, and Breuil, 1943), the following association of industries with beaches has been observed:

(I) Sicilian beach, with rolled Abbevillian *in* the marine deposits. *On* the beach, Clactonian. Breuil (1943) reports an archaic 'Stellenbosch' of Clacto-Abbevillian facies from the 90-metre Sicilian beach at Abderahman near Casablanca.

(II) A 60-metre beach.

(III) Tyrrhenian beach (30 metres). *On* it, Acheulian. In

[1] A variety of the Clactonian, preceding the true Mousterian in the region of the Garronne (Languedoc); hence the name, given by Breuil (1932, p. 131).

superimposed sub-aerial deposits, Levalloisian, Micoquian and 'Moustero-Tayacian'.

(IV) Monastirian beach ('Grimaldian'). In superimposed sub-aerial deposits, 'Tayaco-Mousterian' (cf. North African Aterian), followed by Oranian (upper Palaeolithic or later).

The notable feature of both the Portuguese and the Moroccan successions, provided that the geological identification of the beaches can be verified, is the presence of some kind of 'Abbevillian', or Clacto-Abbevillian, in the Sicilian beach. This beach is, in our chronology, pre-Pleistocene. These two areas thus afford valuable evidence for the Pliocene age of man as a tool-maker, and corroborate the earlier discoveries made by Reid Moir in East Anglia, to which we shall turn presently.

D. PALAEOLITHIC OF BRITAIN

The scarcity of loess sections in Britain has the deplorable consequence that geological dating of Palaeolithic sites is possible only in a small minority of cases. Owing to their westerly position the British Isles had, throughout the Pleistocene, a relatively more oceanic climate than the continent of Europe. This fact is clearly expressed in the cold phases by the prevalence of solifluction over wind-borne deposits.

Furthermore, this climatic factor, combined with the multiplicity of ice-centres and the present geographical isolation of the British Isles have rendered difficult the establishment of the succession of climatic phases and the subsequent correlation with the Continental succession. Both these objectives have been brought nearer to attainment in recent years, largely owing to research carried out in East Anglia (where the morainic country resembles north Germany in many respects) and in the lower Thames (where the eustatic fluctuations of the sea-level can be discerned).

In our attempt to establish a chronology of the British Palaeolithic, we have therefore to concentrate our attention chiefly on these two areas. But even here, the number of Palaeolithic sites which can be dated on geological evidence is small, and the reader is likely to be disappointed when he discovers that such famous localities as Hoxne and High Lodge in East Anglia are not described or fitted into the detailed chronology. Fortunately, some sites which are of first-rate importance in the chronology of the European Palaeolithic, such as the pre-Abbevillian sites of the Ipswich, Norwich and Cromer districts, and Clacton-on-Sea, as the type site of the Clactonian, can be dated fairly closely on geological or palaeontological evidence.

East Anglia, climatic succession. East Anglia occupies a prominent place in the chronology of the Palaeolithic, largely as the result of J. Reid Moir's labours. It is to him that we owe the

discovery of great numbers of pre-Abbevillian implements in sections which can be dated in the framework of the detailed relative chronology.

The general succession of climatic phases in East Anglia has been discussed many times over. Following petrological work on moraines at Cromer by Solomon (1932), it has become reasonably certain that two great ice-sheets (*North Sea Drift* and *Great Chalky Boulder Clay*) passed over Norfolk into Suffolk, and that possibly a third, somewhat smaller one (*Little Eastern*), followed. The latest evidence of glaciation is the *Hunstanton Boulder Clay*, of an ice-sheet which only just touched East Anglia in the north-east.

The correlation with the continental succession (Boswell, 1936; Zeuner, 1937, 1944) is suggested by palaeontological evidence for the age of the Cromer Forest Bed as Antepenultimate Interglacial, by the relative intensities of the glaciations, and other evidence.

In the Cromer and Norwich districts, the vast ice-sheet of the North Sea Drift Glaciation, partly of Scandinavian origin, is evidenced by part of the Cromer Till and by the Norwich Brick Earth. It was followed by an interglacial (represented by the Corton Sands), a second great glaciation (Great Chalky Boulder Clay), and one or more later and smaller ice-sheets. This sequence resembles closely that of Elster, Saale, and later glaciations in north Germany (Zeuner, 1937; 1944, p. 114). It suggests an Elster age for the North Sea Drift, and this is confirmed by the palaeontological evidence for the age of the Forest Bed which underlies it.

The Cromer Forest Bed, which is a fluviatile-estuarine deposit, caps the series of the East Anglian *Crags*, mostly marine shore deposits which, for a long time, were regarded as Pliocene. But, as Boswell (1936, p. 151) pointed out, even if one follows Lyell's original classification, based on the percentage of living and extinct mollusca, the Red Crag and all the later Crags have to be placed in the Pleistocene.[1] In fact, since Ray Lankester in 1912 suggested that the Crags should be considered of Pleistocene Age, this view has been substantiated again and again. In particular, Lankester, and after him Moir, have persistently claimed that the later Crags correspond to the Early Glaciation ('Günz'). It can even be shown that two sudden increases in the number of arctic shells, in the Newer Red Crag [2] and in the Weybourne Crag, indicate the two phases of the Early Glaciation (Zeuner, 1937, p. 148).

The basement beds of the Crags and their implements. At the base of the Crags, in nearly every section, a detritus bed occurs

[1] Only the Coralline Crag may have to be left in the Pliocene.

[2] Professor P. G. H. Boswell has pointed out to me that when he was working with Harmer, the latter always emphasized that the 'northerners' began to arrive, as individuals, in the Oakley Horizon of the Older Red Crag. It is conceivable, therefore, that part of the Older (Waltonian) Red Crag might have to be added to EGl_1.

(*basement bed*, *Bone Bed*), about one to three feet thick, consisting of coarse flints and fossils of various ages from the London Clay up to the time when the bed was formed. It is clearly a transgressive formation and likely to antedate the overlying Crag Beds but slightly, being simply the first deposit laid down when the formation of the coastal deposits began. Thus, there is a basement bed beneath the middle Red Crag in the Ipswich district of Suffolk, one that underlies the Norwich Crag in the Norwich district of Norfolk, and one that is found in the Cromer district of Norfolk beneath the Weybourne Crag and the Forest Bed. These basement beds may be continuous, merging into each other, but their ages are not the same, that below the Red Crag being the earliest, and that below the Weybourne Crag and the Forest Bed, the latest.

Red Crag (*Ipsvician*). Nevertheless, the basement beds being transgressive formations, they contain pebbles, fossils and implements derived from land-surfaces and the destruction of earlier deposits. As regards the implements, this question has been studied by Reid Moir, especially for the Ipswich area (Moir, 1935) where he distinguished five groups of implements, group I being heavily rolled and patinated, and group V almost fresh. To these 'sub-Crag' implements has to be added the industry of Foxhall Hall near Ipswich (not to be confused with the much later site of Foxhall Road in Ipswich), where two horizons with implements were found *in situ* in the Red Crag. This series of primitive flake implements and rough core implements among which the rostro-carinate is typical may, for convenience's sake, be referred to as the *Ipsvician* stage (see p. 183). Boswell (1936, p. 153) has carried further the analysis of these implements which have acquired fame partly because they were not accepted as human artefacts by some archaeologists, partly because others accepted them as evidence for Tertiary man.

Classifying the implements according to geological horizon and degree of rolling and patination, the Foxhall Hall series is clearly the latest; it fixes the upper limit of the Ipsvician *in* the middle Red Crag, so far as our evidence goes. The implements recovered from below the middle Red Crag (many from the Bramford Pit; Boswell 1927, pl. i) can, following Moir and Boswell, be classified as follows. Group V cannot be later than the middle Red Crag or, in the detailed chronology, the first phase of the Early Glaciation. Group IV, which is patinated, would be somewhat earlier than this, and the others, especially groups I and II, which constitute 90 per cent. of the known material according to Boswell, are heavily rolled, striated and patinated and may well be *considerably* older than Group V, though how much older we are unable to judge. Since, however, the Plio-Pleistocene boundary, as defined by Pilgrim (1944) and Zeuner (1944, p. 174) in accordance with the views of Lankester, Moir, Penck and many others, lies just before the first

phase of the Early Glaciation, we must admit that Moir's contention, that tool-making man lived in the late Tertiary, is reasonable, though there is no need yet to follow him in tracing man back to the upper Miocene. Thus, Moir has the great merit of having shown, by his discoveries below the Red Crag of Suffolk, that man dates back to the late Pliocene, where he was roughly contemporary with the Villafranchian, Sicilian and possibly Calabrian phases. Within the last two or three years, this conclusion has been corroborated by the finds of primitive industries in and on beaches in Portugal and Morocco, which are regarded as Sicilian.

Norwich Crag (*Norvician*). In the basement bed of the Norwich Crag which, in the detailed chronology, has to be placed in the interstadial $EGl_{1/2}$, numerous implements have been found (Clarke, 1906; 1911; Lankester, 1914; Moir, 1927, 1930; Sainty, 1929). Beside many flake tools, they include a small number of rostro-carinates, and a rather large number of primitive hand-axes. On the whole, this industry looks advanced compared with the Ipsvician to which it is closely related. Moir (1930) regarded it as comparable with the early Abbevillian, chiefly on the evidence of the rough hand-axes. This industry has been called Icenian by Ray Lankester, and Icenian II by Leakey (1934), but Boswell (1936) pointed out that this term, which is the geological term for the Norwich, Chillesford and Weybourne Crags, is apt to be misleading. This is the more so since Leakey called the Ipsvician ' Icenian I ', thus extending the archaeological term to the earlier Crag to which the geological term does not apply. It seems advisable, therefore, to use another word to designate the Norwich Crag industry. *Norvician* may be suitable.

As an example of a section which has yielded Norvician implements, that from Thorpe near Norwich, excavated by Sainty (1929) is reproduced here (fig. 62).

Weybourne Crag and Forest Bed (*Cromerian*). The third district where implements have been found in a Crag basement bed is that of Cromer, on the north coast of Norfolk. This is the youngest of the series. The basement bed rests, as usual, on Chalk and is in places covered by the Weybourne Crag, which was deposited during EGl_2.

The basement bed continues beneath the Forest Bed (ApIgl) in close proximity to the Weybourne Crag (Sainty, 1929; Moir, 1930, p. 222). It is very unlikely that the stone beds seen beneath the Weybourne Crag and that seen beneath Forest Bed deposits are different formations. Now, it is easy to understand that a transgressive basement bed was formed beneath the marine Weybourne Crag, but it is difficult to see how a precisely similar formation could develop at the bottom of a river or estuary such as that of the Forest Bed. Since Clement Reid (1882, p. 8) it has been known that the Forest Bed does in places overlie the Weybourne Crag.

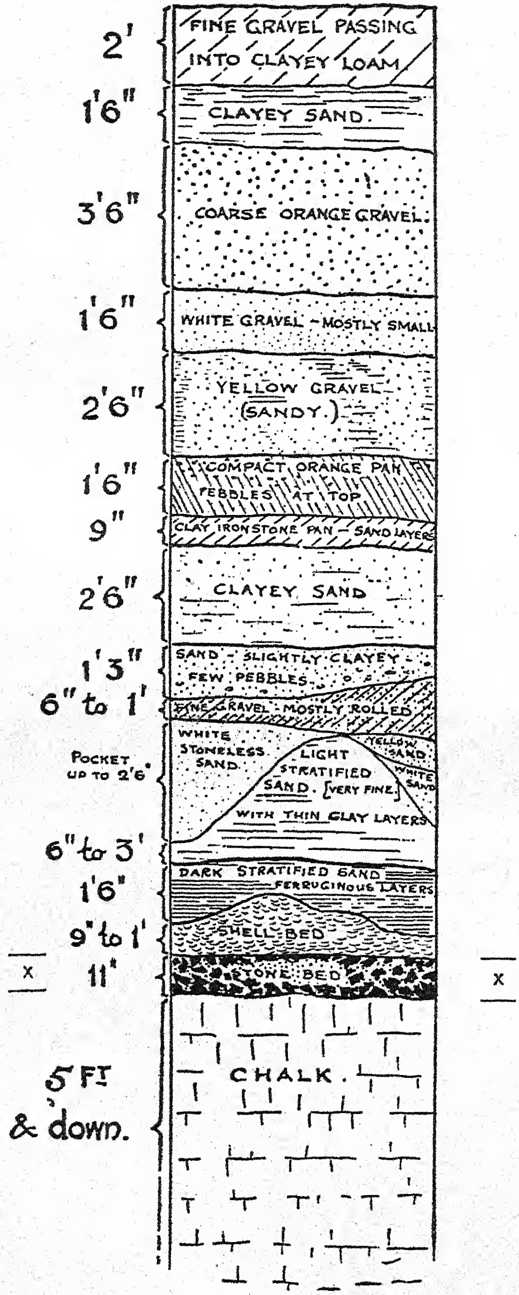


FIG. 62.—Section of Norwich Crag at Thorpe, near Norwich, Norfolk, excavated by Mr. Sainty.—Reproduced with permission, from Sainty (1929).

The Forest Bed series therefore appears to be the filling of a river bed cut into the Weybourne Crag down to the level of the basement bed. On this view, the stone bed at the base of the Forest Bed deposits is the Weybourne Crag basement bed.

The continuity of the stone bed and the close association of the Weybourne Crag and the Forest Bed in the cliffs at Cromer have induced Sainty (1929) to hold the view that these two deposits are quasi-contemporaneous and indicate a regime of shifting river and coastal deposits like bars and beaches. If the interpretation given in the preceding paragraph is accepted, however, there is no need to go to this length, and the palaeontological difficulty that the marine fauna of the Weybourne Crag is cold, and the terrestrial fauna and flora of the Forest Bed warm, is obviated.

This problem of the precise age of the Stone Bed at Cromer has some bearing on the dating of the Cromerian industry. If the stone bed of Cromer is the basement bed of the Weybourne Crag everywhere, then all the implements recovered from it must be regarded as dating from the second phase of the Early Glaciation. This view is preferred here, for the reasons given. If, however, the stone bed beneath the Forest Bed is regarded as dating from the beginning of Forest Bed times, or if Forest Bed and Weybourne Crag are considered simultaneous deposits and dated on the mammalian fauna of the Forest Bed, the implements would belong to the Antepenultimate Interglacial.

Cromerian implements. Apart from the geological considerations just outlined, there is a typological argument which supports the Weybourne Crag age of the implements. It has been pointed out by Moir, Sainty and others, that the Crag industries form an evolutionary series, from the primitive Ipsvician of the Red Crag (and earlier times) through the Norvician of the Norwich Crag to the Cromerian of Cromer.

The Cromerian industry (Moir, 1924, 1921–4) is particularly well-known from the so-called ‘ foreshore site ’, a flint spread exposed at low-water. There are two kinds of flints here, one having the characteristical ochreous or brown patina of the stone bed. This site appears to be the residue of the stone bed resting on Chalk, broken up by the modern sea. These implements are unusually heavy, and Moir has repeatedly drawn attention to the difficulty modern man would encounter when using these flakes. The same applies to some of the implements found *in situ* in the stone bed, for instance to a giant hand-axe from Sheringham (Moir, 1934), found by J. P. T. Burchell, which weighed over 14 lbs. Moir therefore thinks that the makers and users of these implements must have been of a more powerful built than modern man, and he recalls in this connexion the Heidelberg jaw which is indeed remarkably massive.

The Cromerian industry is more advanced than the Norvician, especially in the greater individuality of the tools. Rostro-carinates have become rare, and the hand-axes are decidedly of an early Abbevillian type. Yet the majority of the tools are made from heavy flakes which give the industry its distinctive character.

Returning to the question of chronology, the Antepenultimate Interglacial of northern France is known as the time of the *typical* Abbevillian. Since the Cromer Forest Bed is of the same interglacial, it is more reasonable to assign the *early* Abbevillian to a somewhat earlier phase. In fact, primitive Abbevillian specimens are now claimed to occur in Sicilian, i.e., pre-Early Glaciation deposits. These typological considerations—which should not be regarded as conclusive chronological arguments—lend support to the view that the stone bed of Cromer is slightly older than the Antepenultimate Interglacial. Its assignment to the base of the Weybourne Crag (EGl_2), therefore, frees the industrial succession from a slight regional discrepancy which otherwise would have to be accepted.

Crag industries, summary. The Ipsvician, Norvician and Cromerian are industries in which flake tools predominate, although core-tools did play some part. These include rostro-carinates, and hand-axes. Moir has shown that the former type is possibly ancestral to the latter in the technical sense, though they occur together both in the Norvician and the Cromerian. While the rostro-carinates practically disappear with the Early Glaciation, the primitive hand-axes develop into the well-known Abbevillian hand-axes. Moir and most other workers regard these core-tools as integral constituents of the industries with which they are found, so that flakes and cores were utilized simultaneously. But Leakey (1934) regards the rostro-carinate—hand-axe series as a different culture, to which he applies Moir's term, *Pre-Chellian*. Geological evidence from the sites so far does not support this separation.

Forest Bed and Cromer Till. On the basement bed, which we ascribe to the Weybourne Crag, rests the Forest Bed series in those places where the Weybourne Crag deposits have been removed by fluviatile erosion. The Forest Bed series consists of a Lower Freshwater Bed, Estuarine Gravels, and an Upper Freshwater Bed. Both the Estuarine Gravels and the Upper Freshwater Bed have yielded artefacts, but these are very rare and not susceptible of cultural classification (Moir, 1936). Their presence, however, is of some importance since Mr. Sainty was fortunate enough to find a beautiful Abbevillian hand-axe in the Cromer Till, the ground moraine which covers the Forest Bed series and contains much material derived from the latter (Moir, 1923). Since man cannot have lived on the spot while the ice was there, it must be assumed that this hand-axe was picked up by the ice, conceivably from the Cromer Forest

Bed. Since the Cromer Till represents the Antepenultimate Glaciation, and probably its second phase, this Abbevillian specimen testifies to the presence of Abbevillian man during the Antepenultimate Interglacial or, at the latest, the first phase or the interstadial of the Antepenultimate Glaciation.

Penultimate Interglacial (*Runtonian*). The later deposits of East Anglia merely confirm the datings of industries obtained on the Continent. In the marine sands which intervene between the two great glaciations of Norfolk, at Runton near Cromer and at Corton, on the coast not far from Norwich, Moir and Baden-Powell found implements which they describe as an industry consisting mostly of small flakes (Moir and Baden-Powell, 1938; Baden-Powell and Moir, 1942). The specimens are mostly unrolled, and Moir says that, 'by reason of the prevalence on the flakes of plain unfacetted striking-platforms,' they 'may perhaps be assigned to an early Clactonian industry' (Baden-Powell and Moir, 1942, p. 217). The age of these sands has been determined as the interglacial between the North Sea Drift and the Great Chalky Boulder Clay by Baden-Powell, i.e. our Antepenultimate Interglacial. Clactonian is characteristic of this interglacial in the Thames valley as in northern France.

Last Glaciation, first phase. Although East Anglia is not devoid of Acheulian and Levalloisian or Mousterian, none of these industries has been found in a position in which unambiguous geological dating is possible. The difficulty is caused by the so-called Little Eastern Glaciation, an ice-sheet of smaller dimensions than the two preceding ones, the limits of which and the chronological affinity of which are not yet decided. It occupies in many ways a position comparable with that of the Warthe Glaciation of north Germany (Zeuner, 1937; 1944, p. 107). A ground moraine called *Upper Chalky Boulder Clay* is believed by many workers to be the deposit of this phase, which was given the name, *Little Eastern Glaciation*, by Solomon. This moraine, however, has not yet been found in a section overlying the two older moraines; its independence has been suggested by the combination of certain sections with two boulder clays, some of which are supposed to contain the North Sea Drift (or an equivalent moraine) plus the Great Chalky Boulder Clay, others the Great Chalky Boulder Clay plus Upper Chalky Boulder Clay. This method of correlation is full of pitfalls, as has been shown elsewhere (Zeuner, 1944, p. 109). If the independent existence of the Upper Chalky Boulder Clay can be established, it would, in the detailed chronology, correspond to the first phase of the Last Glaciation.

A site of great potential importance is Elveden, in the Breckland on the Cambridgeshire–Norfolk border. It was excavated by Paterson and Fagg (1940). Their fig. 3 shows a section (their section C),

in which two boulder clays occur, and between them deposits containing an industry described as 'Upper Clactonian-Acheul'. The two boulder clays are regarded as the Great Chalky and the Upper Chalky Boulder Clays, and Paterson, in 1939, correlated the upper one, though with a question mark, with the first phase of the Last Glaciation. Paterson holds the view that there is a third, oldest boulder clay in the area, corresponding to the North Sea Drift Glaciation.

Last Glaciation, Hunstanton Boulder Clay (*upper Palaeolithic*). The last event in the glacial history of East Anglia is the arrival of an ice-sheet which only just touched the north-west coast, where it left a very characteristic brown boulder clay, the *Hunstanton Boulder Clay*. This is identified with the Hessle Boulder Clay of Lincolnshire, and both are part and parcel of the Newer Drift Glaciation which, on all available evidence, is the chronological equivalent of the Weichsel Phase of the Scandinavian ice-sheet (LGl_2).

At the base of, and scattered throughout, this boulder clay, implements of upper Palaeolithic facies have been found. Moir reported them from the Hunstanton area of Norfolk, and Burchell from below the uppermost boulder clay in Yorkshire (Moir and Burchell, 1930). Additional evidence was brought forward by Moir in 1931. Although the implements are not typical enough to assign them to a substage of the upper Palaeolithic, Moir is inclined to regard them as upper Aurignacian. Their occurrence in genuine Hunstanton Boulder Clay seems to be well established, and Moir rightly concludes that upper Palaeolithic man lived here, or farther north, before or while the ice of this glaciation was spreading. This evidence, therefore, informs us that in this part of England, upper Palaeolithic was present during the advance of LGl_2. It will be remembered that, in northern France, upper Levalloisian survived into this phase, and it will be interesting to see whether such survival did occur in other parts of England (p. 199).

This concludes the rapid survey of the chronology of the East Anglian Palaeolithic. We shall now consider the lower Thames, where sites are available which, at least in part, fill the middle Pleistocene gap of the East Anglian succession.

The Lower Thames valley. The most important sections are crowded in a small area at Swanscombe, near Gravesend. The discovery by Marston (1938) of a skull fragment of a *Homo* cf. *sapiens*, led to the subsequent investigation of the site by a committee (Swanscombe Committee, 1938, report by Hinton, Oakley, Dines, King, Kennard, Hawkes, Warren, Cotton, Le Gros Clark and Morant). This site is the Barnfield Pit at Swanscombe; it may here be taken as the starting point for our chronology. The section is composed of:

Swanscombe, Kent (*Clactonian and Acheulian*).

(F) 'Upper Gravel,' a solifluction deposit with a clayey matrix.

(E) 'Upper Loam.' Decalcified, sandy loam, with a contemporary wedge of a sludge deposit. Contains white-patinated Acheulian hand-axes. Surface at 110 feet O.D., concluding the eustatic aggradation of the river to the Tyrrhenian sea-level. Penultimate Interglacial, probably a late phase. With Middle Acheulian.

(D) Upper Middle Gravel, passing into (E) without break, chiefly consisting of clean yellow sand. At its base, in a more gravelly layer, the skull was found. Middle Acheulian industry.

(—) Erosional unconformity.

(C) Lower Middle Gravel, with Middle Acheulian industry.

(—) Phase of weathering of Lower Loam.

(B) Lower Loam, weathered from above, and with root cavities. No implements.

(A) Lower Gravel, a coarse gravel containing some pebbles of quartzite, &c., probably derived from boulder clay. Industry, Early Clactonian.

(—) Thanet Sand, Eocene.

The succession from (A) to (D) is later than the glaciation which reached the Thames Valley. That this was the Antepenultimate Glaciation ($ApGl_2$) can be shown on other evidence in the Thames Valley. The surface of the aggradation agrees, within a foot or so, with the average height of the Tyrrhenian sea-level, so that the succession from (A) to (D) can only belong to the Penultimate Interglacial. The aggradation was interrupted, perhaps only locally, or, as suggested for instance by Oakley (1937, p. 253), by a phase of general down-cutting, after the Lower Loam was deposited. This Hiatus also corresponds to a break in the industrial sequence, since Early Clactonian (Chandler, 1930 ; Breuil, 1932) occurs in the Lower Gravel, and Middle Acheulian in the upper. The resemblance of this succession with that of St. Acheul has been mentioned before (p. 171).

The Barnfield Pit section, therefore, provides us with evidence for the Great Interglacial age of the Early Clactonian (stage Clactonian II*a*) and of the Middle Acheulian, the latter following the former. Hawkes, in co-operation with Oakley and Warren; made a careful study of this Acheulian (Swanscombe Report, p. 30 ff.) and found that the industry of the Lower Middle Gravel is an Acheulian III (Breuil's classification), that the Upper Middle Gravel, though poorer in implements, contains the same type of industry, and that rare specimens of a more advanced Clactonian (recalling the Clactonian III of High Lodge) occur in the Middle Gravel, mainly at the lowest levels. This Clactonian seems to correspond, according to Oakley (Swanscombe Report, p. 56), fairly closely to the industry of Wangen on the Unstrut (p. 148).

Since, for geological reasons, the aggradation of the Swanscombe gravels, in particular of the Middle Gravel up to the Upper Loam, is considered as a late episode of the Great Interglacial, this section suggests that by that time the Clactonian was approaching the Clactonian III stage, and the Acheulian was still Middle Acheulian. No clear evidence for any Levalloisian has come forward (see, however, Warren's view, Swanscombe Report, p. 47).

Clacton-on-Sea (*Clactonian*). The type site of the Clactonian industry is Clacton-on-Sea, some 45 miles downstream from Swanscombe on the coast of Essex, north of the present Thames estuary. Although it cannot be dated on purely geological grounds, its fauna is typically of the Great Interglacial type. Archaeologically, it is closely related to the Clactonian of the Lower Gravel of Swanscombe, but in view of its slightly more advanced nature, recognized already by Warren, Oakley (in Oakley and Leakey, 1937) classifies it as Clactonian II*b* and regards the deposit as formed in the interval between the Lower and Middle Gravel of Swanscombe. The industry and the site were described by Warren (1922, 1933), Breuil (1932) and Oakley and Leakey (1937); and further notes on the deposits given by Warren (1923, 1934), and King and Oakley (1936). From the chronological standpoint, Clacton-on-Sea is important because it confirms the Great Interglacial age of the Clactonian II.

Dartford Heath gravels (*derived Abbevillian*). If we look for evidence which might fill the gap between the Clactonian II of the Great Interglacial in the Thames Valley, and the Abbevillian of the Antepenultimate Interglacial (incorporated in the Cromer Till) of East Anglia, we have to be content with suggestions drawn from derived, rolled and scratched implements. The gravels of Dartford Heath, generally held to be contemporary with the Swanscombe aggradation, but almost certainly older (Hinton and Kennard, 1905; Zeuner, 1944, p. 267), were apparently aggraded during the first phase of the Antepenultimate Glaciation or in the following Interstadial. These gravels contain broken and abraded Abbevillian hand-axes (King and Oakley, 1937, p. 59), which cannot be younger than these gravels but may well come from the Antepenultimate Interglacial. This suggests much the same chronological position for the Abbevillian of the Thames area as for that of East Anglia, and it agrees with the ApIgl age of this industry established in the Somme.

Furthermore, the Clactonian I appears to go into the gap between the Swanscombe deposits and the Cromer Forest Bed series. Chandler (1930) and Breuil (1932, p. 150) emphasize that the Lower Gravel contains, apart from fresh Clactonian flakes, many which are heavily rolled and striated; Breuil finds appreciable differences between the two series and attributes the striation of the derived series to solifluction. For this reason, and relying on evidence from

northern France (p. 168), he classifies the Clactonian I late in the Antepenultimate Interglacial, though in England there is no geological evidence either for this, or a slightly later (ApGl) age. In either case, it appears conceivable that the Clactonian I is roughly contemporary with the Antepenultimate Glaciation, or perhaps the later part of the Antepenultimate Interglacial.

Bakers Hole, near Ebbsfleet, Kent (Early Levalloisian). The aggradation of the Middle Gravels of Swanscombe (Great Inter-

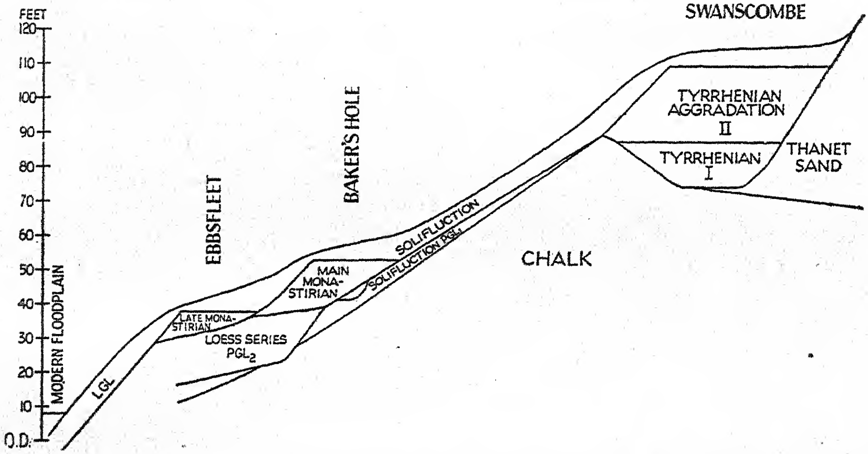


FIG. 63.—Very diagrammatic, and much simplified, section from the Ebbsfleet Valley to Swanscombe, Lower Thames, illustrating the sequence of climatic phases as suggested by the evidence at present available.

After the cutting of the bench at Swanscombe, aggradation (in two stages) to Tyrrhenian sea-level of the Penultimate Interglacial, with Clactonian II and early Middle Acheulian.

Then erosion to low sea-level, and formation of Main Coombe Rock (solifluction) and of some stream-deposited gravel (Baker's Hole) in the cold climate of the first phase of the Penultimate Glaciation, with early Levalloisian at Baker's Hole.

Partial removal of the Coombe Rock suggests a slight break in the sequence (? interstadial $PGl_{1/2}$?), which was followed by deposition of cold gravels (Middle Levalloisian) and loess (second phase of Penultimate Glaciation).

Aggradation of river gravels to the Main Monastirian sea-level followed in the first part of the Last Interglacial (Upper Gravels at Baker's Hole).

Thereafter, the sea-level dropped again, erosion cutting through the Main Monastirian gravels and partly the loess series (Burchell's Ebbsfleet section). A new rise of the sea-level (Late Monastirian) brought the aggradation of the 'temperate loam' of Burchell, in the second part of the Last Interglacial.

This was followed by a further phase, or phases, of down-cutting and solifluction during the Last Glaciation.

Finally, the sea-level rose to its present height.

glacial) was followed by a period of erosion and formation of solifluction deposits of the coombe-rock type (King and Oakley, 1936, p. 60; Dewey, 1932, p. 49; Burchell, 1933). At Bakers Hole, in the Ebbsfleet valley close to Swanscombe, a floor of Levalloisian I–II occurred underneath the coombe-rock (monographed by Smith,

1911). This early Levalloisian, therefore, is earlier than the cold phase evidenced by the down-cutting to a low sea-level and by the solifluction.

The dating of this cold phase is made possible by the deposits which overlie the coombe-rock in the neighbourhood, and to which J. P. T. Burchell has paid special attention. The significance of the evidence has been given elsewhere (Zeuner, 1936; 1944, p. 127 ff.). In a few words, Burchell (1933) showed that the main coombe-rock antedated the Taplow Terrace aggradation of the Thames which, on independent evidence, proves to belong to the Last Interglacial. The coombe-rock, therefore, belongs to one of the two phases of the Penultimate Glaciation. Now, the coombe-rock of Bakers-Hole (usually called Main Coombe-Rock) is cut into and in part even removed down to the Chalk (Burchell, 1935*a*, p. 90) and the resulting valley filled with deposits chiefly of a loessic nature. This second erosion and the subsequent deposition of loess suggest a second cold phase, and the Main Coombe-Rock thus would represent PGl_1, and the loess phase, PGl_2.

Ebbsfleet (*Middle Levalloisian*). Burchell was fortunate enough to find, in the filling which followed the second erosion, and underlying the loess, a gravel with Middle Levalloisian implements (Burchell, 1933; 1936). This, therefore, must be more or less contemporary with the second phase of the Penultimate Glaciation, as it has been found to be in northern France and in Markkleeberg, though this industrial stage apparently lingered on into the Last Interglacial.

Brundon, Suffolk (*Middle Levalloisian*). The persistence of the middle Levalloisian is shown, in southern England, by the section of Brundon in Suffolk (Moir and Hopwood, 1939). A fluviatile gravel rests on a boulder clay which is generally regarded as that of the second great glaciation of East Anglia;[1] and it is covered by solifluction deposits which are attributed to the Last Glaciation. Strictly on geological lines, however, the age of this gravel cannot be established, since the number of climatic phases represented in the section is insufficient. But the inference to be drawn from the geological conditions, namely that the gravel corresponds to the Last Interglacial, is borne out by palaeontological evidence. From his thorough analysis of the mammals, Hopwood concluded that Brundon is demonstrably later than the Ilford deposits, and somewhat later than the Crayford deposits. The latter are predominately of Last Interglacial age, though in part they date back to the loess phase of PGl_2 of Ebbsfleet. This makes Brundon certainly later than the Penultimate Glaciation, and therefore, most probably, Last Interglacial.

[1] Note that Moir calls it *Upper Chalky Boulder Clay*, while in the terminology of the present book it would be the *Great Chalky Boulder Clay*. The very confused terminology of the East Anglian moraines cannot be discussed here (see Zeuner, 1944, p. 101).

The industries found mostly come from the gravel. Moir distinguishes a land surface at the base of the gravel, but after an inspection of the section I am unable to corroborate this view. There is no pedological evidence for a land surface, and the 'manganese layer' must be included in the basal portion of the gravel. The gravel has yielded—

(*a*) in a derived, patinated, striated, or rolled, condition: Early Clactonian, early Acheulian, 'late' (middle) Acheulian, Levalloisian I–II (Baker's Hole type), and some specimens reminiscent of High Lodge (Clactonian III);

(*b*) in a fresh, unabraded and unpatinated condition: a middle Levalloisian comparable with that found by Burchell in his Ebbsfleet sections.

This assemblage suggests that, during the episode of the Last Interglacial when the Brundon gravels were accumulated, middle Levalloisian man was on the scene, and that, in addition to several industries already known to us from the Great Interglacial, and the Penultimate Glaciation, the Acheulian referred to above and the High Lodge Clactonian antedate this middle Levalloisian. Yet, since both Acheulian and High Lodge Clactonian implements are rare in Brundon, this suggestion must not be taken as an established truth.

Halling, Medway valley (*upper Palaeolithic*). The Thames Basin does not provide chronological evidence for the change from lower to upper Palaeolithic. But there is a site, apparently of upper Palaeolithic age, which, in spite of the doubts which have been expressed as to the amount of disturbance suffered by the site, is of interest. It is Halling, some miles upstream from Rochester, on the Medway, a river flowing into the Thames estuary. In the Lower Floodplain Terrace of the Medway, a human skeleton was found, together with a small number of flints (Cook and Killick, 1924; Garrod, 1926). This terrace, which has been called the Halling Stage by King and Oakley (1936), is later than the Late Monastirian phase, from which it is separated by a period of downcutting. It appears to have been aggraded during the interstadial $LGI_{1/2}$ (Zeuner, 1944, p. 133). The typological classification of the flints is difficult. Some specimens recall the industry of the upper levels of the Creswell Crags (Pin Hole and Mother Grundy's Parlour, see p. 196), but a scraper suggests middle Aurignacian. It is evident that the flints found just above the skeleton (top of Cook's layer 5) are upper Palaeolithic, but whether they are middle Aurignacian, or Creswellian, or any other stage, cannot be said with certainty. The importance of Halling lies in the fact that it shows upper Palaeolithic to have been present during the interstadial $LGI_{1/2}$. It will be remembered that Moir found upper Palaeolithic in the boulder clay of what appears to be LGI_2 in East Anglia (p. 188), but the

evidence from the Creswell Crags is at variance (p. 199), suggesting a survival of Mousterian tradition into this phase in Derbyshire.

High shore-lines between Portsmouth and Brighton. The chronology of the Palaeolithic industries, ascertained so far from the glaciated area of East Anglia and from the area of river deposits of the lower Thames Basin, is further substantiated by the finds made in the beaches of the Tyrrhenian and Monastirian phases on the south coast of England. All along the south coast, which appears to have been outside the zone of isostatic disturbance, ancient beach deposits are found which can be referred to the Tyrrhenian level of 32 metres, the Main Monastirian level of 18 metres, and the Late Monastirian level of 7·5 metres. Those of the coast east of Portsmouth contain numerous implements.

Tyrrhenian beach near Chichester (middle to late Acheulian). Fowler (1932) described the exposures in the so-called 100 foot-beach near Chichester. There is a continuous sheet of sand and gravel at 80–90 feet O.D. (Aldingbourne beach), but in pits at Waterbeach and Slindon, marine deposits reach or exceed 130 feet O.D. In these pits, marine sand is overlain by reddish, unstratified, clayey gravel which has generally been regarded as a solifluction deposit (coombe rock). In Marshall's pit, Slindon, the sand and the unstratified gravel are interbedded to some extent (Oakley and Curwen, 1937). From this it would appear that, in the final phase of transgression, the sea was working up some gravel deposit which, perhaps, formed a cliff, and when the sea receded from this level, the cliff collapsed, or other agents spread the gravel over the abandoned sandy beach. This mode of formation of unstratified deposits (pseudo-solifluction) can be observed in many places along the cliff-coast of Essex and East Anglia, the only difference being that they do not last but are sooner or later destroyed by the waves. The climate during the time of maximum transgression of the 100-foot phase, therefore, need not have been cold.

In the underlying sands, moreover, a temperate shell fauna is found.

It is difficult to determine the exact height of sea-level to which these deposits refer. The 80–90-foot level of Aldingbourne probably marks a recessional phase only slightly later than the maximum phase (100 feet and over). In the higher complex, the surface of the sand lies at 120 feet (36 metres) at Slindon, and at 130 feet (39 metres) at Waterbeach (Fowler, 1932). If one regards the former value as close to high-water mark at the time of maximum transgression and makes allowance for the local tidal amplitude, the mean-water level of the '100-foot' beach would have been at about 33·5 metres. This is a very good approximation to values found elsewhere (Jersey, 32–4 metres; mouth of Somme, 32–3 metres; see fig. 46). Waterbeach would then have to be considered

as an exceptional deposit, perhaps part of the storm beach. The mean sea-level, if based on Waterbeach, would have been about 36·5 metres.

Implements have been found at the base of the 100-foot beach (at Netley an Acheulian ovate), in beach gravel at several localities (mid Acheulian hand-axes and early Clactonian), and on the beach-sand, but underneath the supposed coombe-rock, at Slindon Park, an occupation level of developed 'late' Acheulian (Palmer and Cooke, 1923; Calkin, 1934). Since some implements of this level were rolled, the site was occupied when the sea still had access to this level.

It is clear that this beach is the marine equivalent of the 100-foot terrace of the Thames at Swanscombe. The archaeological contents agree at Swanscombe and at Chichester, but in the latter area the so-called 'late' Acheulian came in at the very end of the period of aggradation. There are indications that the same applies to Swanscombe also (Hawkes, in Swanscombe Report, p. 45). It must be noted, however, that the distinction of 'late' from middle Acheulian is a somewhat arbitrary one, and that a new stage of the Acheulian cannot be recognized clearly before the advent of the Micoquian.

A 50-foot level (Main Monastirian) has been distinguished by Palmer and Cooke (1923) only, but its existence has been established at Portland (Baden-Powell, 1930), and the Selsey mud deposit with its warm fauna can be referred to it also (Zeuner, 1944, p. 239). No implements have been found *in* the beach gravels in this area.

Finally, a 15-foot beach is very well developed. At Selsey it forms a headland, far distant from the ancient cliff and, consequently, well below mean sea-level of that time. Locally, however, it rises to 28 feet O.D. No implements have been found *in* it.

Brighton. The 15–25-foot Late Monastirian level extends almost uninterruptedly from Selsey past Bognor to Brighton, where it ends in the cliffs of the Black Rock (White, 1924; Martin, 1929). The marine deposits near Brighton rise locally to 30 feet O.D., and head or coombe-rock is commonly found covering them. Apart from rolled Acheulian, one Mousterian (?Levalloisian) implement has been found *in* the fossil beach at Brighton, and finds made in the Chichester district show that the 'Mousterian' survived this sea-level of 15–25 feet (Palmer and Cooke, 1923, p. 273). The same relationship between the Late Monastirian beach and the Mousterian (Levalloisian) industry has been established in Jersey (p. 178).

The exact height of mean sea-level during this phase, at any rate at Brighton, is difficult to ascertain. Undercuts are rare in Chalk cliffs, and the coast east of Brighton is rapidly being eroded away. Only at Black Rock can the height of the inner edge of the platform be measured, but it has not been done yet. On the

whole, however, this beach lies between 15 and 30 feet above O.D., so that the mean water level is likely to have been very close to 7·5 metres, the average for the Late Monastirian phase.

Thus, the south coast of England affords corroborative evidence for the middle Acheulian being the industry of the Great Interglacial, and for the Mousterian or Levalloisian flake industries being contemporary with, or even surviving, the Last Interglacial.

Pin Hole Cave, Creswell Crags, Derbyshire (Mousterian and upper Palaeolithic). The most important site for the chronology of the industries of the British Upper Pleistocene is the Pin Hole Cave in Derbyshire. It was excavated by Armstrong (1931; 1933; 1939, p. 101 ff.). The section is reproduced in fig. 64.

The strata are sealed by a stalagmite, above which in a superficial earthy deposit a temperate fauna was found containing brown bear, wolf, badger, pig and red deer. In the underlying 'red cave earth', the fauna is predominately arctic in the top layers ('developed Aurignacian'), cool-temperate in the middle (Font Robert level, with *Bison*, horse, red deer, but also reindeer), and cold in the bottom layers (upper Aurignacian and proto-Solutrian, with reindeer, mammoth, woolly rhinoceros, arctic fox, arctic hare. The same cold fauna is contained in the 6 inches of 'Mousterian 3' which underlie the proto-Solutrian and which are usually referred to by Armstrong as part of the lower cave earth, presumably on account of its industry, though in his figure they are included in the upper. The upper, 'red' cave earth rests on a slab-layer with an exclusively cold fauna, which Armstrong interprets as the product of frost-weathering. This sequence, therefore, suggests an oscillation of the climate from cold through moderately temperate (though the reindeer persists!) to cold and, after the formation of the stalagmite, followed by temperate conditions which presumably represent the Postglacial.

I am not inclined to attach so much climatic importance to the covering stalagmite as is done by Armstrong, since this is apparently due to the cave having become increasingly damper in consequence of the gradual blocking of the exit by the deposits. The stalagmite in part penetrated the top of the cave earth, and thus incorporated some of the cold fauna of the latter. This difference of opinion, however, does not affect the climatic sequence.

The lower part of the section (Armstrong's 'yellow cave earth') is subdivided by another slab-layer into an upper and a lower portion. The upper yellow cave earth again shows a 'moderately warm' oscillation in the middle (with 'Mousterian 2'), established on faunal evidence. It is cold above and at the bottom, which indicates the transition from the cold conditions of the lower slab-layer to the more temperate conditions of the upper yellow cave earth, and again back to the cold conditions of the upper slab-

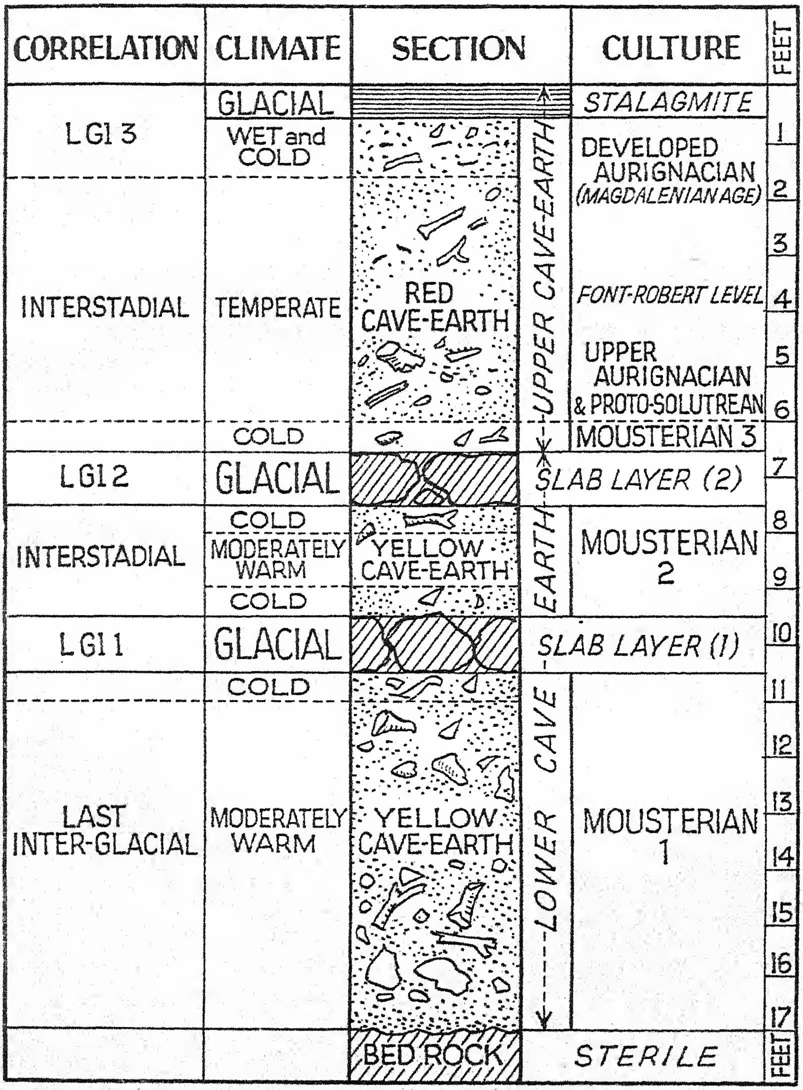


FIG. 64.—Section of Pin Hole Cave, Creswell Crags, Derbyshire, according to Armstrong.—Reproduced from Armstrong (1931), modified.

layer. The lower slab-layer contains an arctic fauna, and so does the uppermost portion of the lower yellow cave-earth. This part of the section, therefore, adds a third, and earliest, cold phase to the sequence.

The lower yellow cave-earth has a fauna containing horse, bison, giant deer, lion, &c. described as moderately warm.[1] It contains a Mousterian industry ('Mousterian 1').

The obvious chronological interpretation of this section was given by Armstrong, when he assigned the three cold phases to the Last Glaciation, and the lower yellow cave-earth to the Last Interglacial. Since, however, he was not then aware that the threefold subdivision of the Last Glaciation had been established on the Continent and that the Hunstanton Boulder Clay (Newer Drift) was likely to represent the second of these, he suggested that the stalagmite corresponded to the Newer Drift. In the light of our present more detailed knowledge, this correlation appears improbable, since the third of the three phases of the Last Glaciation is known to have been much weaker than the first two. This picture is reproduced in the Pin Hole section, where the first two cold phases are represented by periods of frost-weathering, while the third is not. Nevertheless, Armstrong's correlation of the entire complex from the lower slab-layer upwards with the Last Glaciation agrees with the evidence better than any other alternative.

Movius (1942, p. 46) proposes to correlate the stalagmite and the top of the red cave earth with LGl_2, and the upper slab-layer with LGl_1, leaving the lower slab-layer unaccounted for. If this lower slab-layer were absent, this correlation would at first sight appear most suggestive, but the lower slab-layer does call for an explanation. One might be inclined to regard it either as the equivalent of the cool oscillation which has been called Prewürm by Soergel (p. 161), or as a phase of the Penultimate Glaciation. The first alternative is unlikely because that minor phase appears to have produced hardly any frost-weathering. If one nevertheless assumes that its climate permitted as much frost-weathering as evidenced by the lower slab-layer, one is forced to attribute to the upper red cave earth (the supposed equivalent of the Newer Drift Glaciation) an even more rigorous climate. But the top of the upper red cave earth exhibits little evidence of cold; so that it becomes clear that this alternative cannot be upheld.

Lastly, if one relegates the lower slab-layer to the Penultimate Glaciation, one finds it difficult to include the whole of the Last Interglacial in about one foot of upper yellow cave-earth, whilst about six feet of a temperate cave-earth are found below this slab-

[1] The fauna has not yet been published in detail. It is, I understand, being studied by Dr. W. Jackson in Manchester. References to species given here are taken from Mr. Armstrong's published reports.

layer. Furthermore, the fauna does not appear to support so great an age for the lower slab-layer, judging from the expression 'arctic fauna' of slab-layer 1, used by Armstrong. Typically 'arctic' faunas are characteristic of the Last Glaciation. This argument, however, cannot be regarded as conclusive until the faunas of the consecutive layers have been published in detail.

Thus, for the reasons given, the three cold phases of the Pin Hole section are probably to be regarded as the three phases of the Last Glaciation. The ensuing archaeological chronology is most interesting.

The developed Aurignacian of the higher levels is often called *Creswellian*. It is a local, or perhaps British, facies of the Aurignacian with abundant evidence for upper Magdalenian influence (Garrod, 1926, pp. 147, 149, *et al.*). It eventually merges into an Azilio-Tardenoisian, found in the neighbouring cave of Mother Grundy's Parlour (Armstrong, 1925; Garrod, 1926, p. 135), where the transition to the Mesolithic coincides with the change of the fauna from cold to temperate. The Mesolithic therefore appears here at the same time as elsewhere in temperate Europe, namely after the climax of LGl_3, when the climate begins to improve.

The Creswellian itself corresponds to the upper, red, cave-earth, of the interstadial $LGl_{2/3}$, and LGl_3 until the climax. This is, in other parts of temperate Europe, the time of the Magdalenian which, indeed, has had a profound influence on the Creswellian.

In the basal, cold, portion of the red cave-earth, however, a Solutrian influence is noticeable, and this proto-Solutrian horizon emerges from a Mousterian one. The proto-Solutrian and the typical Solutrian are, as far as known, confined to the maximum of LGl_2, and the position of the corresponding horizon in the Pin Hole agrees well with this. The Mousterian which leads up to it, is however an unusual feature.

The Mousterian of the Creswell Crags has been divided into three stages, the earliest of which would date from the Last Interglacial, possibly a late phase. It is, according to Armstrong (1939, p. 103) typical old Mousterian. Below this Mousterian floor, 'the artifacts recovered include flakes of massive Clactonian type which correspond in facies and technique with the Tayacian industry of La Micoque'. The old Mousterian of Derbyshire thus appears to have succeeded a Tayacian, during the Last Interglacial.

The Mousterian 2, of the cave-earth of the interstadial $LGl_{1/2}$, is called a 'typical' one, but its mixture with a bone industry with upper Palaeolithic traits is an extraordinary feature. It may be recalled that Mousterian survived the first phase of the Last Glaciation in the Rhine Valley (Wallertheim, p. 159). But we know that during the following interstadial Aurignacian began to spread. A curious piece of evidence for contemporaneity of this Pin Hole

Mousterian 2 with some Aurignacian is the bull-roarer found by Armstrong (1936).

The Mousterian 3 follows immediately the formation of the second slab-layer, and the fauna is still cold. It must, therefore,

TIME SCALE	CLIMATIC PHASE	CENTRAL EUROPE	NORTHERN FRANCE	BRITAIN
	Pgl	MESOLITHIC		AZILIO-TARDENOISIAN
25000	LGl$_3$	PRE-TARDENOISIAN FINAL MAGDALENIAN		CRESWELLIAN
	LGl$_{2/3}$	MAGDALENIAN		CRESWELLIAN
72000	LGl$_2$	MAGDALENIAN SOLUTRIAN AURIGNACIAN	MAGDALENIAN SOLUTRIAN UPPER / MIDDLE AURIGNAC FINAL LEV.(VI-VII)	PROTO-SOLUTRIAN PIN HOLE MOUSTERIAN
	LGl$_{1/2}$	AURIGNACIAN	AURIGNACIAN ?LEV. VI	PIN HOLE MOUST. AURIGN.
115000	LGl$_1$	MOUSTERIAN		
	LIgl	MOUSTERIAN	LEV. V MICOQUIAN LEVALLOIS V LEV. V MICOQUIAN	OLD MOUSTERIAN MIDDLE LEVALL. CF. TAYACIAN
187000	PGl$_2$	MID. LEVALLOIS-UPP. ACHEUL	MIDDLE ACHEULIAN	MIDDLE LEVALLOISIAN
	PGl$_{1/2}$		MIDDLE ACHEULIAN	
230000	PGl$_1$	CF. CLACTON OR TAYACIAN		EARLY LEVALLOISIAN (I-II)
	PIgl	UNCLASSIFIED FLAKE INDUSTRIES CF. LEVALLOISIAN(?) OR CLACTONIAN	LOWER & MIDDLE ACHEUL LOW. ACHEUL CLACTON II	MIDDLE ACHEULIAN CLACTONIAN II
435000	ApGl$_2$			
	ApGl$_{1/2}$			
476000	ApGl$_1$			
	ApIgl		ABBEVILLIAN CLACTON I	ABBEVILLIAN
550000	EGl$_2$			CROMERIAN
	EGl$_{1/2}$			NORVICIAN
590000	EGl$_1$			IPSVICIAN
	VILLA-FRANCHIAN			

FIG. 65.—Chronology of the Palaeolithic of central Europe, France and Britain. Unconformities between the three areas have not been smoothed out.

be assigned to LGl$_2$, whose climax it apparently just survived, to be replaced by ('to merge into', Armstrong) the proto-Solutrian level. With the proto-Solutrian we are again on familiar ground.

The survival of the Mousterian into upper Palaeolithic times

is borne out, in both levels 2 and 3, by the abundant utilization of bone and the presence of many complex artifacts and ‘amulets’. Armstrong (1939, p. 107) is not aware that similar artefacts have been recorded elsewhere, and he sums up the evidence thus: ‘Taken as a whole, these facts and objects appear to indicate a much higher degree of culture than has generally been assigned to man of the Middle Palaeolithic period.’ By fitting the Pin Hole section into the detailed chronology of the Upper Pleistocene, this has been shown to be the result of the co-existence of the Creswell Mousterian with upper Palaeolithic (Lower and Middle Aurignacian) elsewhere. Even in England, evidence for the presence of upper Palaeolithic man during the interstadial $LGl_{1/2}$ is available (Halling, p. 193), quite apart from Continental sites. Thus, the Pin Hole Cave (and the other caves of the Creswell Crags) afford a most instructive parallel to the survival of the final Levalloisian in northern France.

E. SUMMARY

The evidence for the age of Palaeolithic industries, determined from sections which can be dated by geological or palaeontological methods, or both, without reference to archaeological pre-conceptions, is summarized in the table, fig. 65. The three areas, or provinces, distinguished, central Europe, northern France, and Britain, correspond to what one might call scientific provinces, in which research has proceeded on somewhat independent lines. Nevertheless, the resulting chronologies are found to agree closely.

The table comprises only such industries as have been discussed in the preceding parts of this chapter. Owing to our insistence upon the dating of sites by non-archaeological evidence, many well-known industrial phases do not appear, but the reader who is familiar with any one of the ‘provinces’ can easily complete the picture for himself by adding to this skeleton the probable chronological positions of the missing phases of the Palaeolithic.

The discussion of the significance of this chronology is best reserved for a special chapter which will follow those treating the evidence from the Mediterranean and from other continents.

CHAPTER VII

CHRONOLOGY OF THE PLEISTOCENE AND THE PALAEOLITHIC OF THE MEDITERRANEAN AREA

A. THE CLIMATIC SUCCESSION

While evidence for the detailed relative chronology of the Pleistocene in temperate Europe is abundant, this is not yet so in other areas. This chronology is the back-bone of the absolute chronology as based on the astronomical time-scale. In turning our attention

to the Mediterranean region, therefore, it is necessary to keep in mind that the application of the astronomical method to such an area is tentative.

With this proviso, however, one is justified in making an attempt to extend the astronomical chronology to the Mediterranean, first, because its successful application in temperate Europe renders it highly probable that the same close relation between the stratigraphical succession and the fluctuations of radiation also exists in the adjacent regions. Secondly, the stratigraphical evidence which has been brought forward in the Mediterranean region, notably that from the Lower Versilia in northern Italy and from Mount Carmel in Palestine, already shows that the Mediterranean upper Pleistocene can be explained more satisfactorily by adopting the astronomical method than by any other. This matter has been treated at some length in a different place (Zeuner, 1944, Chapter VII), so that it will suffice here to summarize the most important features.

Main features of the Pleistocene climate of the Mediterranean. Evidence for the Pleistocene climate is available chiefly from the Grotte de l'Observatoire, Monaco, and the Grimaldi caves (44° N.), the coastal plain of the Lower Versilia (44° N.), the Pontine Marshes (42° N.), the Grotta Romanelli (40° N.), and Mount Carmel (33° N.). It is fairly complete for the subdivisions of the upper Pleistocene, but very scanty for the lower and middle Pleistocene. The following generalized statement appears to be permissible:

(1) During the Last Interglacial (Monastirian beaches at 18 and 7·5 metres, with *Strombus bubonius*-fauna), the sea was warmer than at the present day.

(2) The most complete sections, those of the Grimaldi caves and of the Lower Versilia, confirm that there were three phases of cool and damp climate corresponding to the three phases of the Last Glaciation in temperate Europe.

(3) Of these, the first was moderate, and the second the most intense, but climatic evidence for LGl_3 has not been found south of 43° N., so that this phase may have been very weak in the south.

(4) LGl_2, on 40° N. and north of it, can be subdivided into a first, humid, subphase, and a subsequent cold and more continental subphase. On 33° N., however, the climate corresponding to a glacial phase appears to have been humid throughout.

(5) LGl_1 is represented by a humid phase everywhere; it was cool north of 42° N., and temperate to the south of it.

(6) It follows from (4) and (5), that there were latitudinal differences of the climate which were most pronounced with regard to LGl_3, and least pronounced with regard to LGl_1.

(7) It further follows from (4) and (5), that the ordinary type of climatic phase representing a glacial in the Mediterranean is a phase of humid, or oceanic, character which, when conditions were

severe, as during LGl_2, was followed by a cold and continental subphase in the northern part of the Mediterranean.

(8) Climatologically it is to be expected that a *pluvial* of the Mediterranean type falls into three subphases, namely (A) the initial subphase of decreased summer radiation and increased winter radiation, with rainfall more evenly distributed over the seasons than at present, with cooler summers, but not necessarily a greater annual total precipitation. This subphase is called the *pseudo-pluvial*; it favoured the extension of temperate forest in the Mediterranean area. (B) The period of the greatest extension of the ice-sheets in northern Europe, during which the secondary effects of the glaciation (p. 142) affected the Mediterranean, through the deviation of many rain-bringing depressions into the Mediterranean, and through frequent invasions of cold air from the glaciated area. Unsettled weather with much rain and rapid and intense changes of temperature, with frost in the northern Mediterranean. This is the *Pluvial* proper, with pseudo-continental climate north of approximately 40° N. Finally, (C), the period of disintegration of the glacial anticyclone. Rapid return to the present Mediterranean type of climate, with its rainy winters and dry summers.

This deduced course of the climate during a pluvial phase corresponding to a glacial phase in northern Europe is corroborated by the geological evidence as summarized under (7).

(9) A pronounced latitudinal differentiation is to be expected. In the countries bordering the Mediterranean in the south, the secondary effects of the glaciation are likely to have been confined to an increase in the number of rain-bringing depressions, so that subphase (B) would have been mild, and distinguished from subphase (A) merely by an increase of precipitation.

The latitudinal differentiation should have been accentuated by the latitudinal differences in the amount of radiation received. In particular, the summer minimum of LGl_3 grows weaker as one goes south.

Geological evidence confirms this theoretically expected differentiation according to latitude (compare points (3), (4) and (5)).

(10) In accordance with the radiation curves, it is to be expected that the pluvials are doubled, except for the Last Glaciation, which should be represented by three pluvial phases.

Evidence shows that there were indeed three pluvial phases following the Last Interglacial, and the duplication of the pluvial corresponding to the Penultimate Glaciation is suggested in the Grotte de l'Observatoire.

(11) The succession of interglacial, eustatic, high sea-levels (see p. 127) should confirm the succession of climatic phases as based on terrestrial evidence. The Monastirian does so, since it is followed by the three pluvial phases of the Last Glaciation. For the earlier

high sea-levels, however, no detailed correlation can be established, for lack of evidence from contemporary terrestrial deposits. All one can say is that the Calabrian corresponds to the late Pliocene.

Absolute Chronology in the Mediterranean. The palaeoclimatic material summarized in these 11 points permits one to construct a tentative absolute chronology for the upper Pleistocene of the Mediterranean. The 'pluvial' phases which can be correlated with glacial phases of temperate Europe were almost contemporaneous with them, but only the pseudopluvial subphase, which in the geological evidence will appear rather damper than it actually was, corresponds strictly and without retardation to the minimum of summer radiation of the latitude in question. Taking the figures for 35° N. as an average, the three pseudopluvials of the Last Glaciation are dated at 116,000, 72,000 and 22,000 years B.P. But the pluvial proper followed this subphase in each case, in accordance with the retardation of the maximum development of the ice-sheet (see p. 142) and was, therefore, later, possibly by several thousand years.

B. ITALO-FRENCH RIVIERA

We may now turn to a survey of localities, which will help in elaborating several of the points just outlined. The localities have been selected in part for their archaeological importance, and in part for their chronological significance. These two do not always coincide, and the reader is likely to look in vain for some sites he might expect to find. But since this book is concerned with the chronological aspect and is not intended to provide a synopsis of the areas considered, such selection could not be avoided. The localities are arranged in a geographical order, beginning with the classic sites of the Italo-French Riviera, passing southwards through Italy, thence to Palestine, Egypt, Algeria and, finally, the Iberian Peninsula.

Grotte de l'Observatoire, Monaco. The Grotte de l'Observatoire (Boule, 1927, Verneau, 1933), in Monaco, is important because it contained deposits of an earlier age than most other caves. It lies as much as 100 metres above the present sea-level, just below the upper edge of the rock of the mainland, facing the peninsula of Monaco. It is not a sea-cave and differs in this respect from most of the caves to be described subsequently.

Standing in the entrance, one looks down into the excavated chamber of the cave which possesses a rock-wall protecting it against the outside (fig. 66). In the background, the floor drops steeply into an opening, the 'fosse', leading down to some inner chambers with stalactitic formations. As far as we know, however, these were not used by Palaeolithic man. The earliest human traces, i.e. implements, were found in the lower part of the fosse, which is too narrow and steep for habitation. Breuil (1932, p. 186) rightly

suggested that the finds in the fosse had either slipped down or were thrown into it. A regular habitation did not become possible until the larger portion of the fosse had been filled up with sediments and a more or less even floor established. The cave has been completely excavated, but vestiges of the deposits can still be seen *in situ.*

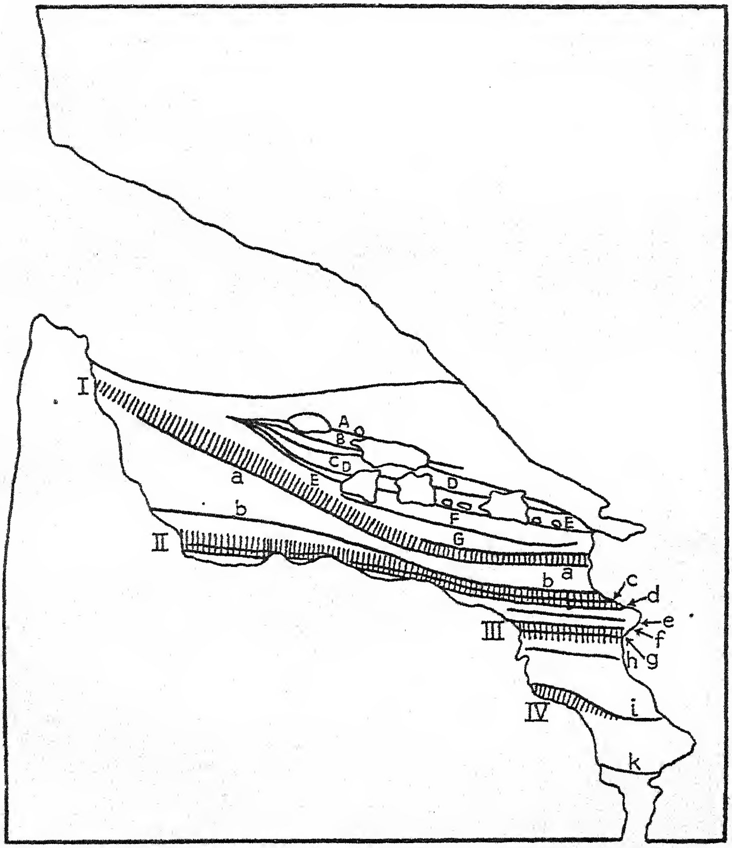


FIG. 66.—Grotte de l'Observatoire, Monaco. Section of deposits.—A to G, and a to k, foyers or occupation horizons.—I, II, III, IV, stalagmitic horizons.—After Boule and Villeneuve (1927), modified.

The section, as described by Boule and Villeneuve (1927) (figs. 66, 67) is characterized by four stalagmitic horizons separated by loose deposits of cave-earth. Since no stalagmite is formed in this cave under the present climatic conditions, the four stalagmitic horizons appear to represent four phases with a climate more humid than the present one.

The deposits of cave-earth are more difficult to interpret. Some preserved patches of the cave-earth which intervened between the first (i.e., uppermost) and second stalagmites show that it was not a cave-earth in the usual sense of the word, but rather a calcareous sand, which could be neither eolian nor water-laid. Whether it was a product of disintegration of limestone, or an unconsolidated travertine or stalagmite, I am unable to say; in any case it does not reveal the climatic conditions of its formation.

The uppermost cave-earth contains numerous large blocks. One is inclined to take these as evidence of a frost climate, and the fauna would corroborate this view, but it is not impossible that the frequent action of fires lit in the cave by Aurignacian man detached the blocks from the roof of the cave.

Fortunately, the fauna recovered from the deposits suggests to a certain extent what the climate of the cave-earth phases was like. Since the fauna was adequately described by Boule (1927), it is sufficient for the present purpose to tabulate it as done in fig. 67. Only a few of the species require special mention.

Among the carnivora, a wild dog is found, *Cuon alpinus europaeus* Bourg., a form of a species now living in the Altai Mountains of Siberia, with close relatives ranging through India into the Malay Archipelago. This species is climatically indifferent.

Two forms of lynx are found in the Grotte de l'Observatoire, the northern form, *Lynx lynx* (L.), and another called by Boule *Lynx pardina* race *spelaea*.[1]

The ibex (*Capra ibex* L.) is very abundant throughout the section, and frequent in the Grimaldi caves also, as well as in some Italian localities as far south as the Grotta Romanelli under the fortieth degree of latitude. In accordance with its present, high-alpine distribution in Europe the ibex has been regarded as an indicator of cold conditions for the Mediterranean area. It is conceivable, however, that, originally, the ibex was merely accustomed to rocky country irrespective of the climate, so long as it did not become too dry in summer. Its present restriction to scattered mountainous localities ranging from Spain to Siberia and south to Yemen and Abyssinia is in part the result of man's interference with these goats; which are extremely shy and at the same time a much esteemed game. Though the Alpine ibex became very frequent at low altitudes in glacial times, it need not have been entirely absent there in the mild interphases, at any rate not along the coast of the Riviera where the Alps rise directly from the sea.

The occurrence of *small* numbers of ibex in a fauna of the Riviera type, therefore, appears to have little climatic significance; if they are very *abundant*, it is likely that good grazing was available at

[1] Miss D. M. A. Bate kindly informs me that this form is osteologically quite distinct from *Lynx pardina* Temminck (recte *Lynx pardella* Miller).

low altitudes, the climate probably being less Mediterranean and more temperate than now. They were also able to withstand a frost climate. The more one goes southwards, however, the more the ibex is likely to have been a form of comparatively cool and humid phases.

The fauna of the lower horizons of the Grotte de l'Observatoire

DEPOSITS	FAUNA	CLIMATE	INDUSTRIES	SUGGESTED CORRELATION	
REDDISH CAVE-EARTH WITH LARGE BLOCKS AND SEVEN LEVELS OF OCCUPATION (A-G) LOWEST FOYER (G)	TEMPERATE FOREST SPECIES, + HORSE, IBEX, REINDEER, ICE-FOX, CUON, CAVE BEAR, HYENA, LYNX PARDINA, LYNX LYNX, MARMOT	COLD FOREST CLIMATE	DEVELOPED AURIGNACIAN		LAST GLACIATION
STALAGMITE I		HUMID		PHASE II	
HIATUS? FOYER a; CAVE-EARTH WITH SMALL ROCK FRAGMENTS; FOYER b	TEMPERATE-FOREST SPEC. + RHINO. MERCKII, IBEX, CUON, CAVE BEAR, HYENA, LYNX PARDINA, [MARMOT POSSIBLY IN BURROWS FROM HIGHEST LEVEL]	TEMPERATE-COOL	MORE CHARACTERISTIC MOUSTERIAN REMINISCENT OF GRIMALDI MOUSTERIAN, CF. UPPER MOUSTERIAN		
STALAGMITE II FOYER c		HUMID		PHASE I	
HIATUS? FOYER d; CAVE-EARTH FOYER e; FOYER f	ATYPICAL FAUNA, BUT NO COLD FORMS	TEMPERATE	TWO ACHEULIAN PIECES, AND FLAKE INDUSTRY REMINISCENT OF MOUSTERIAN		
STALAGMITE III FOYER g		HUMID		PHASE II	PENULTIMATE GLAC.
HIATUS? FOYER h; CAVE-EARTH; FOYER i	ATYPICAL FAUNA, BUT NO COLD FORMS; LYNX PARDINA	TEMPERATE	FLAKE INDUSTRY REMINISCENT OF MOUSTERIAN		
STALAGMITE IV	IBEX, RED DEER, PANTHER, LYNX, CUON, ETC.	HUMID		PHASE I	
HIATUS? FOYER k; CAVE-EARTH	HYENA, CAVE BEAR	TEMPERATE	CLACTONIAN, AND ONE ABBEVILLIAN PIECE		

FIG. 67.—Chronological table for the Grotte de l'Observatoire, Monaco.—For explanation, see text.

is poor. Cold forms have not been found, except for the cave bear, which, though frequent in cold deposits, is not absent from deposits of mild phases in temperate Europe. The few other forms present suggest the climate of a temperate forest.

A richer assemblage of species occurs between the second and first stalagmites. Most of these also are elements of the temperate forest. Some cold types have, however, been mentioned from this level, though the question whether they really came from this level remains open to doubt. The reindeer was queried by Boule himself, the cave-bear is not reliable as a climatic indicator, the arctic fox (*Vulpes lagopus* (L.)) has recently been removed to the uppermost level by Obermaier (1937), and the marmot occurs possibly in burrows descending from the uppermost level. Thus, the fauna cannot be said to be cold; it is temperate, and possibly somewhat cooler than the present Mediterranean climate of this area.

The uppermost cave-earth, above the first stalagmite, contains a fair number of cold elements beside forms of the temperate forest. There are the reindeer, the arctic fox, the northern lynx, the cave-bear, and the marmot, together with the horse, wild boar, red deer, roe deer, ibex, red fox, wolf, *Cuon*, hyena, and others. This fauna does not suggest an arctic climate but rather that of a cold forest not far from the limit of tree-growth. It has a decidedly colder aspect than that of any of the lower layers.

The climatic history of the Grotte de l'Observatoire thus provides evidence for the fourfold repetition of a decidedly humid climate followed by one of temperate forest. The last temperate-forest phase has left a fauna sufficiently ample to show that the climate was bordering on the cold. For the other temperate phases, the evidence is too incomplete to call the climate cold-temperate, though it probably was more like that of present-day central Europe than like the present Mediterranean climate of the locality.

The lithic industries of the Grotte de l'Observatoire were described by Boule, who gave excellent figures. There are also short descriptions by R. Verneau in the Catalogue of the Monaco Museum (1933). H. Breuil made the important discovery that the large flakes of the basal layers are Clactonian (Breuil, 1932), and recently Obermaier (1937) published an account of the industries of this and other Mediterranean localities. Boule not only discussed the affinities of the Mousterian and upper Palaeolithic industries; he also recorded the levels carefully. This is especially important as regards the two Acheulian pieces found lying on the rock beneath the second stalagmite. A short summary of the industries is included in fig. 67.

Clactonian was found below the lowest stalagmite, Acheulian below the second stalagmite, upper Mousterian between the second and first stalagmites, and upper Aurignacian (so-called Grimaldian) above the first stalagmite.

If one accepts the current theory that humid phases in the Mediterranean area correspond to glacial phases in the north, the succession of industries in relation to the climatic phases appears to be roughly the same on the Riviera as in west and central Europe

(compare fig. 65). The four humid phases would, on the archaeological evidence, represent the second and first phases of the Last Glaciation, and the two phases of the Penultimate Glaciation, Clactonian belonging to the Great Interglacial, Acheulian occurring (together with a mousterioid industry) in the Last Interglacial, upper Mousterian between the two phases of the Last Glaciation, and developed upper Palaeolithic after the second phase of the Last Glaciation, when the climate was still cold.

The section of the Grotte de l'Observatoire, however, does not afford geological evidence for the correctness of this correlation; it is merely suggested by observations made elsewhere. For proofs that this correlation is in its outlines correct, it is necessary to turn to other localities of the Mediterranean area.

Caves of Grimaldi. The famous caves of Grimaldi near Mentone lie only about 8 miles east of Monaco. They are quite close to the sea, at a locality known as the 'red rocks', Rochers Rouges in French, Baoussé-Roussé in Provençal, Balzi Rossi in Italian.

For these caves, we are fortunate in possessing a comprehensive memoir by Boule, Cartailhac, Verneau and de Villeneuve (1906–19), which describes the excavations carried out under the direction of Prince Albert I of Monaco. More recently, the Istituto di Paleontologia Umana has resumed work on these sites (Graziosi, 1937).

Grotte du Prince. Without exception, the Grimaldi caves appear to have been carved out by the sea during the Monastirian, i.e., the Last Interglacial. Whether the process took place during the Main or the Late Monastirian cannot be decided except in the Grotte du Prince. In this cave (fig. 68), a horizon of rock-boring shells (*Lithodomus*) is found at 22·7 metres above the present sea-level. This cave, therefore, was carved out by the sea during the Main Monastirian phase. Since the corresponding marine deposits filled the cave up to 10 metres above present sea-level, i.e., somewhat higher than the Late Monastirian sea-level, the cave would have been inhabitable during the latter part of the Last Interglacial, at about the time of the Mousterian of Weimar-Ehringsdorf.

This is borne out by the strata which subsequently accumulated over the marine deposits, forming a detrital cone. At the base of the cone, resting immediately on the marine deposit, an occupation layer (E of section) was found, with Mousterian accompanied by a decidedly warm fauna including *Hippopotamus* and *Elephas antiquus*. In the higher occupation levels, the *Hippopotamus* is absent, but some ibex appear. If this small change indicates a deterioration of the climate, it must have been a very slight one. The Mousterian continues.

A marked change, however, occurs in the uppermost layers of the cone. The occupation layers (for instance, B, fig. 68) are no longer on the cone, but in a protected position behind it, and the

fauna has changed, now comprising the reindeer, the marmot, and numerous ibex. The industry is still Mousterian.

The same applies to the topmost occupation level (A), though a long blade, and possibly some other implements, remind one of the oncoming Aurignacian. In view of the superficial position of this layer, however, these upper Palaeolithic specimens may be interpreted as intrusions.

It is certain that the Mousterian here lasted from the warm, latter, part of the Last Interglacial right into the, presumably first, cold phase of the Last Glaciation. For this reason, A. C. Blanc (1937) referred to this section in order to disprove Penck's contention

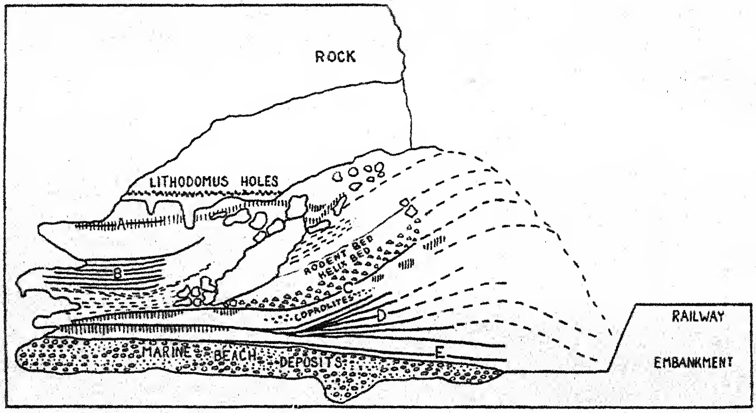


FIG. 68.—Grotte du Prince, Grimaldi. Section of deposits.—A to E, foyers or occupation horizons.—Vertical hatching, stalagmitic levels.—After Boule (1906), modified.

that the whole Mousterian was earlier than the Last Glaciation (Penck, 1936).

The recent excavations of the Istituto di Paleontologia Umana have shown that both in the Barma Grande and in the Grotte des Enfants, both situated close to the Grotte du Prince, the Mousterian complex is overlain by an Aurignacian sequence. The absence of the later deposits in the Grotte du Prince is due to the fact that this cave was filled with debris in Mousterian times, so that it was no longer a convenient place to live in later on.

Grotte des Enfants. The stratigraphy of the Aurignacian series is clearest in the Grotte des Enfants.

The cave, the Grotta dei Fanciulli of the Italians, derives its name from the two skeletons of children found by Rivière in the uppermost beds. When the Prince of Monaco took up systematic excavations, more skeletons were discovered, among them two which, according to Verneau, have negroid characters. All these

human remains were associated with upper Palaeolithic. Traces of Mousterian were found at the very base of the section, near the floor of the cave. The excavations by the Istituto di Paleontologia Umana in 1928 (Graziosi 1937), however, uncovered a pocket in the floor, sealed by stalagmite and containing a series of Mousterian deposits.[1]

Graziosi mentions that the Mousterian of the Grotte des Enfants below the hard layer at which the earlier excavations had stopped, was associated with a *cold* fauna; it thus probably corresponds to the *upper* portion of the section in the Grotte du Prince. In the cultural horizons uncovered by the Prince of Monaco and his staff (numbered from A at the top to L at the bottom), layer L which rested immediately on the above-mentioned stalagmitic horizon, still contained flints of Mousterian appearance. Obermaier (1937) says, apparently referring to this layer L, that the Mousterian contained *Rhinoceros merckii,* a species of a mild climate and fond of parklands. With the foyer K, Aurignacian commenced abruptly. It was a 'typical' Aurignacian according to Obermaier.[2] The foyers I, H, and G contained a woodland fauna with wild boar, red deer and roe deer, wolf and hyena; and the only species which might, though need not, point to cooler conditions were cave bear, ibex and horse. From layer F upwards, however, ibex and reindeer became frequent. They were associated with a 'Grimaldian' industry (Obermaier's Epi-Aurignacian).

The section thus shows two cold phases, one associated with upper Mousterian and one with Grimaldian. They are separated by a typical Aurignacian accompanied by a fauna of a mild climate, but possibly preceded by some Mousterian surviving into this mild phase.

The two cold phases thus evidenced are *a priori* likely to be the first and second phases of the Last Glaciation of northern Europe. That LGl_3 is not represented in the sections so far discussed, is shown by independent evidence for this particular phase from the Riparo Mochi to be described presently.

It is noteworthy that the Mousterian may have survived LGl_1 for a short time, whilst the Aurignacian comes in during the interstadial between LGl_1 and LGl_2, appearing in its typical, not primitive, form. These datings recall similar ones derived from the sections of Wallertheim and Linsenberg in the Rhine Valley, and northern France, they will be discussed in the archaeological summary of this chapter (p. 239).

Riparo Mochi. The continuation of the Grimaldi succession is

[1] Another little cave was opened to the left of, and immediately adjoining, the Grotte des Enfants. It was named Grotta del Conte Costantini and contained upper Palaeolithic as well as Mousterian, and a cold fauna.

[2] I.e., presumably Middle Aurignacian.

provided by a set of new sections discovered by A. C. Blanc (1938). They lie half-way between the Grotte des Enfants and the Grotte du Prince. The locality which consists of rock debris in front of a shelter, has been called Riparo Mochi. The upper part of the section of trench A (the only one so far excavated to a considerable depth) is composed of:

Beds a, b, c. Up to 60 cm. of powdery earth with limestone fragments, containing a hyper-microlithic industry including Mesolithic implements like burins of Tardenoisian type.

Bed d. Up to 1 metre of uniform, compact earth, without fossils or industry.

Bed e. Up to 1·5 metres of limestone breccia, cemented by stalagmite in certain places, with a macrolithic industry of upper Palaeolithic appearance, with large flat blades and with short flat, sub-circular scrapers of a type found in the French Magdalenian and the north African Capsian.

Bed f. Up to 2·7 metres of limestone debris, but unconsolidated, and mixed with a larger amount of brown earth. It is full of ashes, charcoal and other evidence of foyers. The industry is of a 'microlithic upper Palaeolithic' type and 'can perhaps be attributed to an upper Grimaldian'. Some types of implements (e.g., burins of Noailles) are present which have not yet been found in the Grimaldian of the caves.

This sequence of deposits is younger than those reported from the caves. Its importance is evident. It continues the succession of industries up to the Mesolithic and at the same time suggests a third, weaker, humid phase by the partial cementation of Bed e. The presence of an industry of possibly Magdalenian or Capsian affinity agrees well with the discovery of Magdalenian associated with the third phase of the Last Glaciation at Lake Constance and at Meiendorf in Holstein. In Germany as at Grimaldi, the Mesolithic follows this last cold (or humid) phase of the Last Glaciation.

Riviera, summary. The table on page 213 is a summary of the chronology of the Palaeolithic relative to the climatic phases as suggested by the evidence of the Riviera caves.

C. ITALY

Lower Versilia. The succession of the greatest importance from the climatic point of view is that of the Lower Versilia, the coastal plain which lies at the foot of the part of the Apennines called Apuan Alps (pl. XVI, fig. A). It now consists of a flat coastal bar with peaty marshes behind, several kilometres wide. The marshes are replacing a lagoon of which only a lake is left, the Lago di Massaciuccoli. Sand is extracted at this lake by means of pumps and dredgers, and it is here that masses of Palaeolithic implements have been recovered. The section was further explored

		Mesolithic
Last Glaciation	Phase 3	Upper Palaeolithic with elements reminiscent of Magdalenian or Capsian
		Upper Grimaldian
	Phase 2	Grimaldian (developed, or Epi-Aurignacian)
		Aurignacian, typical Mousterian
	Phase 1	Upper Mousterian
	Last Interglacial	Mousterian Mousterioid industry, and Acheulian
Penultimate Glaciation	Phase 2	
		Mousterioid industry
	Phase 1	
	Great Interglacial	Clactonian, and one doubtful Abbevillian piece

with the aid of borings. The geological and archaeological work on this locality has been carried out by A. C. Blanc (1935, 1936*a*, *b*, 1937*a*, *b*). The plant remains have been studied by Tongiorgi (1936, 1937) and by Marchetti and Tongiorgi (1937).

The succession (for details, see Zeuner, 1944, p. 182; compare fig. 69) may be summarized and interpreted as follows, beginning with the earliest recognizable event:

(A) The sea-level at — 90 metres, receding to even more than this, leaves behind deposits with marine shells on the submarine platform.

(B) As (A) proceeds, terrestrial and freshwater deposits spread over the exposed marine deposits. First phase of the Last Glaciation (LGl_1).

(C) The sea rises again, overwhelms the terrestrial deposits of (B) and extends its realm to the foot of the mountains. Maximum sea-level of this phase at least — 60 metres, possibly higher. Climate mild. Interstadial $LGl_{1/2}$.

During the later part of this phase, the rate of the rise of sea-level appears to have slowed down, and a coastal bar with a peaty marsh behind it developed (early part of (D)).

(D) The conditions just described continue, but the sea-level begins once more to drop, the climate becomes cool and continental. Sea-level drops by an unknown amount. Second phase of the Last Glaciation (LGl_2).

(E) The sea-level rises again, at least to — 12 metres and transgresses over the coastal bar and peat of (D), destroying a portion of

the earlier deposits and eventually reaching the foot of the mountains. Climate again mild, '*Purpura*-beds'. Interstadial $LGl_{2/3}$.

(F) A new recession begins, and as the sea retreats, exposing the surface of the deposits (E), sands are laid down, probably in the shape of beach-ridges and dunes. From this level, large numbers of implements have been recovered. Relying on signs of wind-action on some of the implements, Blanc suggests that they come

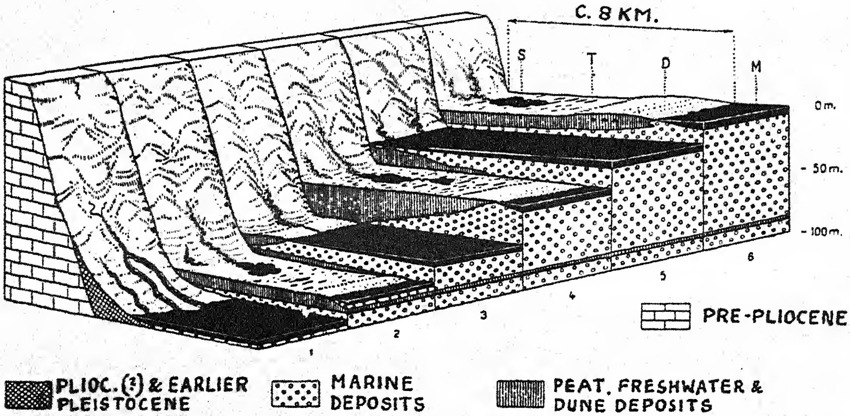


FIG. 69.—Development of the coastal plain of the Lower Versilia, northern Italy, according to A. C. Blanc (1935), from Zeuner (1944). 1. Stage A. 2. Stage B. 3. Stage C. 4. Stage D (regression of sea not clearly shown). 5. Stage E. 6. Stages F and G (regression not clearly shown). S. Lago di Massaciuccoli. T. Peat marsh. D. Coastal dune. M. Sea.

from an eolian pebble horizon at a depth of about − 7 metres. Blanc summarizes his results concerning the implements as follows (A. C. Blanc, 1937*a*, p. 637):

> The tools, which number more than 2,000, can be divided into a Mousterian assemblage and an Aurignacian assemblage. The latter could be subdivided, according to differences in typology and condition, into an older and a younger Aurignacian group, the latter of the Grimaldi type.
>
> A few pieces suggest the presence of a Mesolithic level, and a few tanged arrow-heads may indicate that Neolithic man was also present in this littoral marsh.
>
> The Mousterian assemblage shows a rather advanced technique. The Abbé Breuil, who examined the industry, believes it to belong to a final stage of the Mousterian.

(G) Behind the deposits of (F), freshwater is ponded up while the climate turns cool and humid and the sea-level is low. Third phase of the Last Glaciation (LGl_3).

(H) Finally, the sea-level rises again, to its present height. New

beach deposits and dunes are added to, and mixed with, those of (F), producing the flat, sandy beach-bar which at the present prevents the sea from flooding the marshes lying farther inland. Peat is formed in the marshes and the climate resembles that of to-day.

Prehistoric industries in the Lower Versilia. The numerous implements found by Blanc in this section all come from (F). They were not collected *in situ*, but sucked up by the pumps from below water-level and may be derived from any horizon of this deposit. Blanc has spared himself no trouble in trying to determine the implementiferous level, or levels, with the hardly satisfactory results summed up under (F), above. Many implements appear to come from about — 12 to — 14 metres, i.e., 5 to 7 metres *below* the level of the lacustrine clays (G). Since any implements coming from higher levels will get into the pumps as well, and since the upper portion of the sands classified under (F) may have been deposited as late as during phase (H), one cannot be surprised to encounter Neolithic and Mesolithic implements in this assemblage.

The intriguing problem is the occurrence of Aurignacian and Mousterian implements in large quantities at a level in the section which cannot be lower than — 14 metres. Geologically speaking, this level is later than the interstadial LGl_2/LGl_3. On the other hand, since the lacustrine deposit of LGl_3 lies at about — 6 metres, the Palaeolithic level, or levels, is likely to ante-date this cold phase. Thus, the Aurignacian–Mousterian assemblage would lie in deposits dating from the beginning of the third phase of the Last Glaciation.

Clearly, this result is at variance with the evidence obtained elsewhere in the Mediterranean and in temperate Europe, since (*a*) Grimaldian, ' older ' Aurignacian and developed Mousterian have nowhere been found to be contemporary ; (*b*) only the Grimaldian has been found to straddle the early part of the interstadial LGl_2/LGl_3, and none of them has been recovered from deposits of the third phase of the Last Glaciation.

Two ways of interpreting this state of affairs are possible. The first is to accept the evidence as proof of local survival of these industries, particularly of the Mousterian. This line is taken by Blanc, who published three papers on this subject (1938*b*, *c*, *d*). The second is to contest the geological dating. Since the first alternative has been so ably proposed by A. C. Blanc, the second, hitherto neglected, may be discussed in some detail. It must be borne in mind, however, that there is at present no means available of deciding which alternative is correct.

If the deposits containing the implements were made up of river gravels one would find it quite natural that several industries are mixed and would assign to the deposits the age of the latest of the industries, considering the others as derived. Thus, the archaeological phase of the Versilia-level (F) would be Grimaldian,

and the older types, including the Mousterian, derived from older deposits. All depends, therefore, on the character of the deposit containing the implements. Nobody has ever seen the deposits *in situ*, but at — 7 metres, or 5 to 7 metres above the level from which most implements are pumped up, a horizon of wind-worn pebbles exists, and the entire series might be regarded as eolian, representing coastal dunes. Flints, however, cannot be blown about, and if they are exposed to the wind and re-embedded in sands of wandering dunes, they would inevitably come to lie in the same or a *lower* horizon, but not in a higher one. If the series (F) is purely eolian, therefore, Blanc must be right in stating that the Mousterian of the Versilia survived into the third phase of the Last Glaciation.

On the other hand, the sands of (F) need not be purely eolian; they can be of a composite marine-eolian origin as, indeed, most coastal beach deposits are. The waves take up sands from the surface of the submerged shelf, i.e., from deeper levels, and throw them on to the beach, where a flat ridge or bar is formed. From this, sand is readily picked up by the wind and transformed into coastal dunes. If, therefore, the deposit (F) were of composite marine-eolian origin, wave-action would have transported Mousterian implements, washed out from lower levels, into positions above the sea-level of that period, and the 'continental' sands (F) resting on the *Purpura*-beds would then be contemporary with the Grimaldian, as explained previously.

Yet another possible explanation of the implementiferous deposits is afforded by the lower peat (D), which is in a compressed condition. It may be that coastal dunes and beach-ridges of different ages are incorporated in deposit (F), and that the compressed peat (D) was formed at a much higher level than that in which it occurs to-day, perhaps nearly as high as the implementiferous sands. Part of these sands may be contemporaneous with part of the lower peat, and the present low position of the lower peat be due to compression after its formation.

A certain amount of compression and, therefore, of depression of the lower peat from the altitude-level of its formation down to that in which it is now found, *must* have taken place, an exception being only the basal stratum of the peat. How much the ensuing vertical displacement amounted to, however, cannot be estimated, but one has to admit the possibility at least of older beach-ridges and coastal dune deposits occurring at levels in which the *Purpura*-sands or even the implementiferous sands appear elsewhere. If this is so, or if this was so at any time before the *Purpura*-sea destroyed such deposits, the occurrence of Mousterian implements in the sands classified under (F) finds a more satisfactory explanation.

Since nobody has been able to study the implementiferous sands

in situ, the question of their age and origin has to be left open. I am confident that, in the course of time, A. C. Blanc's continued survey of the locality will provide the answer, but for the time being caution is advised in basing conclusions on the presence of Grimaldian, Aurignacian and Mousterian in level (F) of the Versilia section. The local survival of final Mousterian into the third phase of the Last Glaciation has to be admitted as possible, though it would not affect the interpretation of other sections in the Mediterranean, where the prehistoric chronology agrees to a very high degree with that of temperate Europe.

Pontine Marshes. Another district of great palaeoclimatic and archaeological interest are the Pontine Marshes, about 30 miles south of Rome. Again it is to A. C. Blanc that we owe to the investigation of the sections (various papers, 1935 to 1939).

The Pontine Marshes differ from the Lower Versilia in several important respects, chiefly in the replacement of the transgressive deposits of the Versilia by dune sands. In other words, the accumulation of dune sands and beach-ridges here proceeded at so fast a pace that the rising sea was at no time able to overwhelm them. This is due to more favourable local conditions, the volcanic and other deposits of the area of Nettuno and Anzio providing large quantities of easily eroded material which is redeposited between this area and the limestone island of the Monte Circeo in the south (pl. XVI, fig. B). The lagoon behind the coastal sand belt thus created constitutes the Pontine Marshes proper; it is comparable with the lagoon of the Lower Versilia.

A detailed discussion of the deposits may be found in Zeuner (1944, p. 186), as well as in Blanc's numerous original papers among which that of 1937 (*a*) is probably the most readily accessible. The most important section is that of the Canale Mussolini (fig. 70), at the second weir (Briglia II), which may be summarized and interpreted as follows (from the surface downwards):

—. Surface, with Neolithic.

(A) Reddish, chiefly eolian sands, with upper Palaeolithic, including La Gravette blades (Blanc, 1938*e*) and Grimaldian (Obermaier, 1937; Blanc, 1936*a*). Not younger than interstadial $LGl_{2/3}$.

(B) Yellow sands. Mousterian near base, upper Palaeolithic frequent in the upper 1·5 metres.

—. Unconformity.

(C_1) Greyish-green sands with calcareous concretions. *Elephas primigenius, Equus hydruntinus.* Artefacts Mousterian, but an 'early Aurignacian influenced by Mousterian is perceptible in the uppermost layers' (Obermaier, 1937; Blanc, 1937*a*, *b*). LGl_2 according to Blanc, cold-continental climate.

(C_2) Reddened, cross-bedded sand with *Elephas primigenius*

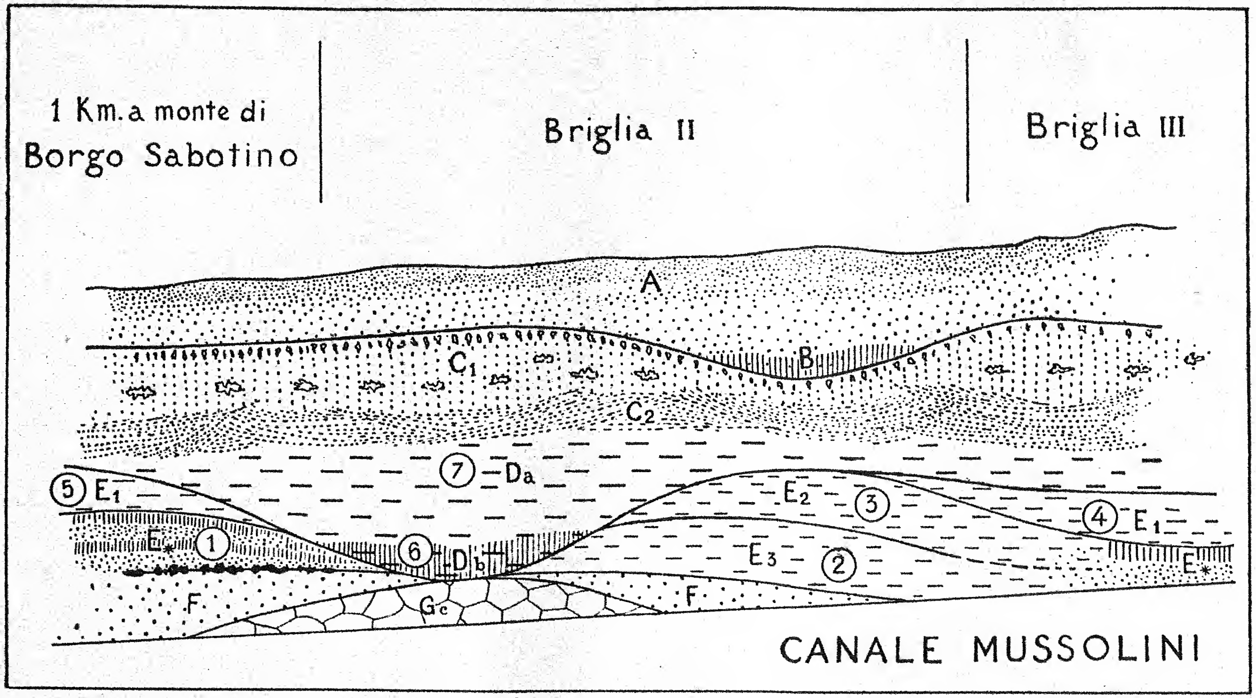


FIG. 70.—Section along the Canale Mussolini, Pontine Marshes, middle Italy, at 'Briglia II'. For lettering, compare text, p. 217.—After Tongiorgi (1937), from Zeuner (1944).

supposed to come from this deposit, but not found *in situ*. Possibly dunes of high sea-level during interstadial $LGl_{1/2}$.

(D) Grey sands, sometimes argillaceous, with plant remains. *Abies alba* indicating cool and humid conditions. *Elephas primigenius* and Mousterian. LGl_1.

—. Unconformity.

(E) Lacustrine peaty beds with flora at first mild, but *Abies* immigrating. Transition from Last Interglacial to first phase of Last Glaciation.

(F) Beach sands with *Strombus* fauna, not exceeding 10 metres above sea-level. Second part of Last Interglacial (Late Monastirian).

The chronological interpretation of the section is uncertain with respect to the separation of the first and second phases of the Last Glaciation. That (C_1) corresponds to LGl_2 is, however, reasonably certain, since one arrives at this determination whether one starts from the Late Monastirian beach deposits at the base of the section, or from the top. As regards the latter approach, it is necessary to supplement the section by a morphological feature, namely the narrow strip of lagoon which separates the belt of red dunes ((A) of the Canale section) from the white dune which is being formed by the sea at the present day. This lagoon affords evidence for a phase of low sea-level separating the phase of the red dunes from the phase of the modern high-sea-level (pl. XVI fig. B), and this oscillation is most adequately explained on the theory of glacial eustasy as the equivalent of the third, and last, phase of the Last Glaciation.

Archaeological succession of the Pontine Marshes. If one accepts the chronology of the deposits as outlined above, implements of the following industries occur (not necessarily in an underived condition) in deposits of the following climatic phases :

Postglacial and Recent : Neolithic.

Last Glaciation, phase 3 : sterile.

Interstadial LGl_2/LGl_3 : Aurignacian (La Gravette blades and Grimaldian), at lower levels Mousterian.

Last Glaciation, phase 2 : Aurignacian influenced by Mousterian above, Mousterian below.

Interstadial LGl_1/LGl_2 : sterile.

Last Glaciation, phase 1 : Mousterian.

In northern France and Derbyshire, the lower Palaeolithic (final Levalloisian and Mousterian, with distinct upper Palaeolithic influences) lasts into the second phase of the Last Glaciation, to be replaced during the same cold phase by a developed form of the upper Palaeolithic (pp. 172, 196). And this happened while in adjacent areas the Aurignacian established itself in the course of the interstadial $LGl_{1/2}$ and continued throughout the second phase of the Last Glaciation.

Since, in the Grotte de l'Observatoire and the Grimaldi caves, the upper Palaeolithic was well established during LGl_2, a local survival of the Mousterian at least into LGl_2, as postulated by Blanc, suggests itself for the Pontine Marshes also. It is noteworthy that an Aurignacian influenced by Mousterian appears temporarily during LGl_2.

Whether this survival lasted into the next interstadial, $LGl_{2/3}$, is doubtful. The occurrence of Mousterian in the lower portion of the yellow sands (B) can be explained either as (*a*) evidence for a portion of these sands being contemporary with layer (C_2), dating from the first interstadial of the Last Glaciation, or (*b*) being due to wave action which threw implements picked up at lower levels on to the beach-ridge, where they were subsequently incorporated in the dunes, or (*c*) as evidence for the survival of Mousterian into this phase. It is at present impossible to choose between these alternatives. (*a*) might conceivably be tested in the field, though it is difficult to separate dune deposits of different age unless fossil soils intervene; (*b*) raises the more general question of the occurrence of pebbles in dune sands, which is not confined to the Pontine Marshes and the Versilia. Miss Gardner (1937) mentions that in the Fayum pebbles are found in dune sands on a water divide, in a position which excludes wave-action almost entirely; whilst observations on Recent coastal dunes show that, during gales, pebbles are thrown on to the dunes. Finally, (*c*) implies that the Mousterian survived into the interstadial LGl_2/LGl_3, and that the Aurignacian either co-existed or disappeared temporarily.

Future research, especially careful investigation of new sections, will no doubt provide the answer to the problem of the survival of the Mousterian in middle Italy. There are, for instance, the numerous sea-caves of the Monte Circeo, the promontory bordering the Pontine Marshes on the south. These caves were mostly carved out by the sea of the Monastirian phase, and many contain Mousterian and Aurignacian beds. The best known are the Grotta delle Capre and the Grotta del Fossellone (Blanc 1937*c*, 1939*b*), but recently Blanc has made a preliminary study of a good many other caves (1938*f*), among them one which contained a skull of *Homo neanderthalensis*.

Grotta Guattari with Homo neanderthalensis. This cave, the Grotta Guattari (Blanc 1939*a*, *c*, 1940; Zeuner, 1940) was completely sealed by rock-waste. When opened, it revealed a floor strewn with fossil bones, and with a human skull lying on it. Only preliminary reports are available so far. The accompanying fauna indicates a climate of the woodland type. Cold elements are absent, unless one counts ibex as such. A Mousterian industry was found at the entrance, covered by the debris which blocked the cave.

Blanc is inclined to think that, as in the other caves of the Monte

Circeo, the cultural stratum rests on the deposits of the Monastirian beach. Since the cave is only 5 metres above sea-level and the maximum height of the lower Monastirian sea-level is 8 metres, the cave was used by man after the beginning of the regression of the sea which was to culminate in the first phase of the Last Glaciation, but before the local climate deteriorated to any great extent. This is the earliest possible date for the skull, the latest possible being the beginning of the second phase of the Last Glaciation when thermoclastic weathering could for the last time have produced the quantities of rock-waste which sealed the cave. The Neanderthal skull of the Grotta Guattari thus proves to be younger than the two skulls discovered at Saccopastore near Rome, to be discussed presently.

The skull itself (pl. XXIV, fig. B) shows a large fracture over the right eye, due to a violent blow. The occipital foramen was enlarged artifially, after the manner of the modern Melanesian extracting the brain for culinary purposes. No other human bones, except a mandible possibly belonging to the skull, were found, and the skull lay in the middle of a circle of stones. Blanc concluded from these circumstances that the cave contained the remains of a ceremonial feast of cannibals.

Saccopastore, Homo neanderthalensis. At Saccopastore, near the confluence of the River Aniene with the Tiber, just upstream from Rome, two Neanderthal skulls associated with a Mousterian industry were found in a gravel pit (Sergi 1929, 1935 ; Breuil and Blanc, 1935, 1936 ; Blanc, 1938*g*, 1939*d* ; Köppel, 1935). Both skulls lay in fluviatile deposits of the Aniene, but evidence of wind action is found in the uppermost layers of the section (Breuil and Blanc, 1936).

Köppel (1935), and Breuil and Blanc (1935, 1936) agree that this deposit was formed during the Last Interglacial. The aggradation of the terrace in which the human remains of Saccopastore are incorporated, can probably be correlated with one of the sea-levels of the Monastirian phase. The history of the lower Tiber and its affluent, the Aniene, is exceedingly complex, much more so than Lipparini (1935) believed, whose views were criticized by A. C. Blanc (1935*c*). Volcanism may have interfered with the eustatic rhythm of down-cutting and aggradation. The data which can be derived from the papers by A. C. and G. A. Blanc, Köppel, Sergi, Lipparini, Verri and others suggest that the system of terraces of the Tiber resembles that of the Thames (*a*) in the aggradations running into high-sea-level deposits, and (*b*) in the benches dropping into a sunk channel which, near the Porta S. Paolo in Rome, reaches down to at least 50 metres below sea-level.

The Saccopastore deposits, the surface of which is at 21–23 metres, cannot be older than the beach deposits of the Main Monas-

tirian phase which are preserved at the foot of the hills towards the coastal plain, as for instance at Palidoro (A. C. Blanc, 1936*e*), at a height of 19 metres above sea-level. If the aggradation of the river at Saccopastore is contemporaneous with the rise of the sea-level to this beach, the skulls would date from the early part of the Last Interglacial (Main Monastirian). This suggestion is supported by indications that the next younger aggradation plain of Tiber + Aniene, which is commonly regarded as the modern floodplain (16 metres at the mouth of the Aniene) appears to connect with the Late Monastirian sea-level at the mouth of the Tiber.

On the other hand, the fauna accompanying the skulls and Mousterian implements contains, apart from *Hippopotamus* and *Bos primigenius*, the extinct Mediterranean ass, *Equus hydruntinus*, a steppe form (G. A. Blanc, 1936). The bed containing the skulls also produced six species of terrestrial snails, three of them with one specimen each, the three others (*Candidula profuga* A. Schm., *Zenobiella incarnata* Müll., *Theba cartusiana* Müll. ssp. *complanata* Monte) frequent but represented by small specimens. Kennard, who determined the mollusca from Saccopastore, stated that this impoverished, small-sized assemblage indicates either a cool climate or unfavourable local conditions. Its association with *Equus hydruntinus* suggests a dry phase, with steppe conditions. This is all that can be deduced from the evidence. The interpretation in terms of climate, however, is ambiguous. Kennard and Blanc are inclined to accept the evidence as a sign of cooler conditions and therefore of the very beginning of the first phase of the Last Glaciation. This is the latest possible date for the Saccopastore skulls. The more conclusive climatic evidence from the Versilia and the Pontine marshes, however, shows that the phases of the Last Glaciation were initiated not by a dry steppe phase but by a humid or oceanic phase, and there is reason to believe that the first phase was humid throughout in middle Italy. It is more likely, therefore, that the steppe phase of Saccopastore is part of the Last Interglacial rather than the beginning of the Last Glaciation. This is corroborated to some extent by the snail fauna of one of the beds overlying the skull stratum. It has yielded a fauna of at least 16 species (Breuil and Blanc, 1936, p. 11) which are definitely characteristic of a humid and shady forest in a mild climate.

Thus, as regards the geological age of the Saccopastore skulls, one can either follow Blanc and place them late in the Last Interglacial or at the beginning of the Last Glaciation, or otherwise early in the Last Interglacial. It will be remembered that a similar alternative existed at the Monte Circeo. In both cases, Blanc favours a 'late' age, and in both an 'early' age is suggested by part of the evidence. In either case, however, Blanc is right in maintaining that the Saccopastore skulls are relatively older than the

Monte Circeo skull. As regards the climatic chronology of the Mediterranean Pleistocene, it can be said that the steppe phase of Saccopastore is either a phase of the Last Interglacial, or, if contemporary with the beginning of the Last Glaciation, a local phenomenon. The botanical evidence of the Pontine Marshes (only 60 km. from Saccopastore) and of the Versilia suggests that, normally, the climate was humid at the beginning of the Last Glaciation.

The surroundings of Rome are certainly one of the most promising areas for Pleistocene research in Italy, with Saccopastore and its human remains, the terraces of the Tiber connected with volcanic deposits, and the marine beaches in the region of the mouth of the river. Palaeolithic implements other than Mousterian have come to light also; G. A. Blanc has described an Abbevillian hand-axe (1935), and A. C. Blanc a Clactonian flake (1936*d*).

Grotta Romanelli. The Grotta Romanelli is a sea-cave on the Adriatic coast of Apulia, below 40° N. lat. For some time its abundant lithic industry was the subject of controversy, some Italian archaeologists regarding it as Neolithic. But authorities like Issel and Mochi (1912) recognized its Palaeolithic character. The issue was finally settled by G. A. Blanc (1921, 1930) who excavated the cave with great care and discovered evidence for climatic phases contemporary with the Last Glaciation. A description of this site is found also in Vaufrey's book on the Italian Palaeolithic (1928).

The section (fig. 71; pl. XVII, figs. A, B) may be summarized and interpreted as follows, the lettering being taken from G. A. Blanc, and beginning with the earliest deposit:

(K) Resting on an irregular rock-floor at about 7·5 metres above low sea-level, a beach conglomerate is found which, on altimetric evidence, can be correlated with the Late Monastirian phase of the Last Interglacial. On its surface, a discontinuous layer of ash and charcoal with bones of *Hippopotamus*, fallow-deer, &c., indicates a warm climate. Some flint blades and several limestone flakes have been recovered from this horizon, the flakes being described by G. A. Blanc as 'analogous to those which have been reported from the Grimaldi caves and the Grotte de l'Observatoire'. This implies that they are not upper Palaeolithic in type.

(I) Angular rock-waste up to one metre in thickness, in places with traces of decalcification and loamification. The fauna still indicates a Mediterranean climate. Faint beds of charcoal and ashes, and a few atypical flint and limestone flakes are the only evidence of the presence of man.

(H) Stalagmitic horizon, about 20 cm. thick. Climate more humid. Fauna poor, apparently temperate rather than warm (hare and fox present). First, humid, phase of Last Glaciation.

Once more the presence of man is evidenced by faint horizons of

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charcoal, with burnt bones, but worked stone has not yet been found.

(G) The 'Terra Rossa', a purplish-red, crumbly deposit of fine earth with small angular pieces of limestone, about 0·8 metres

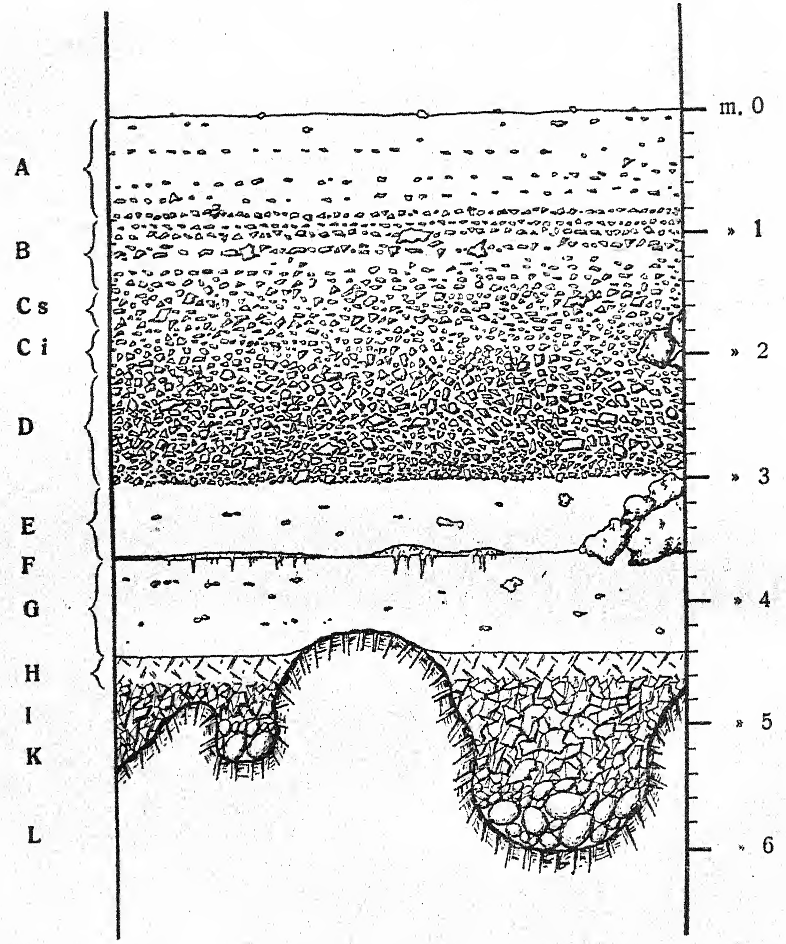


FIG. 71.—Schematic section of Grotta Romanelli, southern Apulia. For lettering, see text.—After G. A. Blanc (1921), from Zeuner (1944).

thick. Probably of composite origin, weathered soil from the neighbourhood of the cave, and some eolian sand, carried by wind into the cave and mixed with debris from the roof. The fauna is warm and comparatively dry. *Hippopotamus* and *Elephas antiquus* exclude a cold climate, two bustards indicate grasslands, fallow-deer

and red deer suggest the presence of some woodlands. Interstadial $LGl_{1,2}$.

The presence of man during this phase of genial climate is confirmed by the discovery *in situ* of a number of stone implements. There are blades, points, scrapers, discs made from ends of blades or from short flakes, a ' départ de burin ', a flake from a pebble, a spherical core, and a flat hammerstone of hard limestone. G. A. Blanc considers this industry as reminiscent of the upper Aurignacian of west and central Europe and also of the Capsian of North Africa. He emphasized the importance of the fact that, here, an upper Palaeolithic industry is found associated with a fauna comprising *Hippopotamus* and *Elephas antiquus*. Vaufrey (1928, p. 61), however, was inclined to call this industry Mousterian, but at the time when he pronounced this view Blanc's figures of the specimens (1930) had not yet appeared.

(F) Discontinuous layer of stalagmite, up to 5 cm. thick, indicating a short, humid, phase. From the evidence provided by (E) to (A), it has to be inferred that this stalagmite was formed during the pseudopluvial subphase of LGl_2.

(E to A). The ' Terra Bruna ', a brown, earthy deposit stratified by layers of fine sand and angular rock-waste. Blown into the cave by wind and interstratified with local debris, but climate cooler than during the formation of the ' Terra Rossa ', as indicated by the brown colour and the abundance of rock-waste in (C) and (D) which suggests thermoclastic (?frost) weathering. Thickness, over 3·5 metres.

Fauna in agreement with the geological evidence for non-Mediterranean, comparatively cold conditions. Warm-Mediterranean elements replaced by those of northern temperate Europe. Among the birds are found a remarkably large number of species which are now restricted to more or less northerly regions, for instance the great auk. ' Pluvial ', of a continental character, second subphase of LGl_2.

The Terra Bruna abounds in specimens of worked flint. They have been described by G. A. Blanc. Vaufrey (1928) too published some figures of implements from Romanelli. The industry belongs to the major group of the upper Aurignacian and can perhaps be classified as a variety of the Gravettian of Garrod (1938), or the Grimaldian (Vaufrey). A characteristic feature is, however, the presence of microburins, which have been specially studied by A. C. Blanc (1939*e*). These are a feature of the Mesolithic of temperate Europe (Azilian and Tardenoisian), so that Blanc speaks of a precocious appearance of Mesolithic technique and implements in this deposit. The chronological difference is striking indeed, since (as will be shown presently) the microburins appear during the second phase of the Last Glaciation in southern Italy, and only after the third phase in temperate Europe. In the lower Capsian of North

Africa, however, microburins are found, and this industry is regarded by Garrod (1938, p. 21) as roughly contemporary with the Upper Aurignacian. It would appear, therefore, that the upper Aurignacian of southern Italy was influenced by the lower Capsian of Africa.

The upper Aurignacian of the Terra Bruna of Grotta Romanelli has further yielded bone points, some with engraved marks (?marques de chasse), a series of perforated teeth of deer, and a number of limestone blocks with engravings. Engravings, some representing conventionalized human figures and animals, are found also on the walls and the roof of the cave (A. C. Blanc, 1938*h*, 1940*b*; Graziosi, 1932).

Thus, in the Grotta Romanelli, the upper Palaeolithic is found to have been present during the entire interstadial $LGl_{1/2}$, i.e. perhaps slightly earlier than in many places farther north. It will be seen that the same applies to Palestine, though there the industrial phases of the upper Palaeolithic are not the same. Such differences will ultimately enable investigators to state the routes of immigration of upper Palaeolithic man. First attempts in this direction have been made by Garrod (1938) and A. C. Blanc (1938*b*, *c*, 1939*e*). We shall return to this interesting matter in the summary, p. 239, and again in Chapter IX.

Italy, summary. The Italian evidence covers only the upper Pleistocene in any detail. Following the clearly recognizable warm Late Monastirian phase of the Last Interglacial, three humid, or cool, phases can be distinguished, of which the second was decidedly cold and continental, though apparently immediately preceded by a more humid subphase. The three phases of the Last Glaciation can thus be correlated with three pluvial phases in Italy. Of these, the second was the most intense, and the third appears to have been decidedly weak.

Homo neanderthalensis was present in Italy in the Last Interglacial and during the first phase of the Last Glaciation. This agrees with northern Europe. The upper Palaeolithic appears during the first interstadial of the Last Glaciation in the south of Italy; since no Mousterian was found in the deposits of this phase in the Grotta Romanelli, it may be that the upper Palaeolithic was present here since the very beginning of the interstadial, whilst in temperate Europe and on the Riviera, the Mousterian appears to have lasted into this phase. But this chronological difference is slight, and it is based on negative evidence only. In the coastal plains of the Versilia and the Pontine Marshes, however, Mousterian may have continued into LGl_2 and perhaps even survived this phase. This claim of local survival of the Mousterian requires further confirmation, though it finds support in a similar survivals in northern France and Derbyshire. On the other hand, neither in the Versilia nor in the Pontine

Marshes are Mousterian and upper Palaeolithic as clearly separated stratigraphically as one could wish. The question may therefore be raised whether they were chronologically distinct, whether they co-existed for some time; or, at least in part, were constituents of one and the same, transitional, mixed, industry.

D. THE SOUTHERN SHORE OF THE MEDITERRANEAN

Palestine, Mount Carmel caves. Among the countries bordering the Mediterranean on the south, Palestine stands out as the only one where, up to the present, thorough work has established a sequence of pluvial phases with which the succession of prehistoric industries can be correlated. It is the work of the Misses D. M. A. Bate and Dorothy Garrod on the caves of Mount Carmel; its outstanding importance lies in the fact that it has conclusively proved that the number of damp phases, or pluvials, of the upper Pleistocene is at least two, and that they were preceded by another humid period which appears to correspond to the Penultimate Glaciation. It is clear, therefore, that theories explaining the pluvial phases, which require one pluvial for each glaciation, or one pluvial for each two glaciations, can no longer be upheld.

The deposits of the caves of Mount Carmel were described by Garrod and Bate in a comprehensive monograph (1937). Two of the caves are particularly important from our point of view, namely Tabun and Wad, and the following summary of the succession is chiefly based on these. A diagram (fig. 72) will help in understanding the various changes. The fluctuations in humidity of the climate are expressed by the relative frequency of fallow-deer (a woodland form) and gazelle (a steppe form), a method which has been applied by Miss Bate with great success.

At the time of the formation of the earliest fossiliferous layer, Tabun (F), the fauna as a whole suggests a warm and damp climate. Upper Acheulian is present.

In the following stratum, Tabun (E), forest predominated, and the uppermost Acheulian (Micoquian) was present. Towards the end of this phase, grasslands extended their domain and attained to a maximum while the next two layers were being formed, Tabun (D) and (C). These contain lower Levalloiso-Mousterian.

A Neanderthaloid female skeleton, and a male jaw, were found in level C of the Tabun cave. This proves that Neanderthal man was contemporary with the lower Levalloiso-Mousterian of this comparatively dry phase which, as will be shown later, represents the latter part of the Last Interglacial. In the neighbouring Skhul cave, however, a deposit containing the same industry, but a damper fauna (Bate, 1937, p. 148), with a frequent large *Bos*, and with fallow deer more common than in Tabun C, yielded burials of nine individuals with mixed *H. sapiens* and *neanderthalensis* characters,

some approaching *H. sapiens* closely (McCown and Keith, 1939). According to Bate, 'heavier rainfall had started, prior to the wet period of Tabun B', which indicates the beginning of the first pluvial phase corresponding to the Last Glaciation. These human remains will be discussed further in Chapter IX.

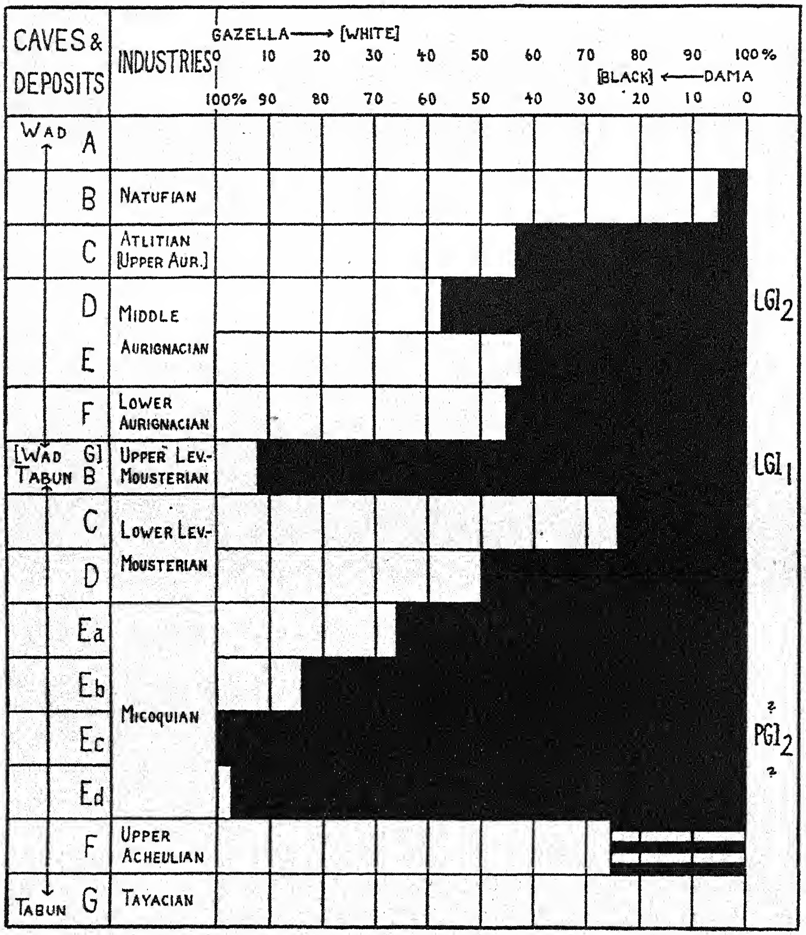


FIG. 72.—Relative frequency of Gazelle and Fallow Deer, indicating climatic conditions, in the deposits of the Mount Carmel caves, Palestine. Prehistoric industries on the left.—Modified, after Bate, in Garrod and Bate (1937).

The dry phase of Tabun (D) and (C) was followed by a long period of forest conditions, suggesting on the whole a damper climate. Two maxima of forest development occurred, one during the upper Levalloiso-Mousterian, in Tabun (B) and Wad (G), and the other

during Wad (D) with its middle Aurignacian. They are separated by a drier phase with lower and early middle Aurignacian, in Wad (F) and (E).

Following this double maximum of humidity, conditions have tended to become increasingly drier. Wad (C), with Atlitian (upper Aurignacian), shows this, and so do the Mesolithic deposits of Wad (B). This Mesolithic ('Natufian') contains the domesticated dog. Miss Bate (1940) has found indications that the Mesolithic was followed by a slightly damper phase, which however did not persist. This suggestion is corroborated by other evidence from the Sahara and southern Arabia (p. 246).

Now, as to the correlation of the climatic phases with the glacial phases of Europe, there are three pluvial phases available, not counting the post-Mesolithic one which belongs to the Postglacial. It is impossible to correlate these three pluvial phases with the three phases of the Last Glaciation since (*a*) the last two damp phases are more closely linked, and separated from the first by a more intense and prolonged dry phase than that which separates them from one another, and (*b*) the fauna changes suddenly at the beginning of the second pluvial. A similar change in the terrestrial fauna marks the *beginning* of the Last Glaciation in Europe. It is likely, therefore, that the second and third pluvials of the Mount Carmel succession correspond to the first and second phases of the Last Glaciation in temperate Europe. The first pluvial of Mount Carmel should then represent the Penultimate Glaciation. If this interpretation is correct, the third phase of the Last Glaciation has either left no traces in Palestine, being too weak in this southerly latitude, or evidence is accidentally missing from the Mount Carmel sections. Miss Garrod has in fact pointed out that there is a gap in the archaeological record of the Wad cave, between layers (C) and (B), which is filled in part by the succession of the Kebarah cave (p. 242). This cave, therefore, deserves special attention from the palaeoclimatic point of view.

Archaeological evidence, as furnished by Miss Garrod, confirms this correlation in a most convincing manner. The succession of industries in relation to climatic fluctuations is, *broadly speaking*, much the same in Palestine and in Europe. During the Last Interglacial, the Acheulian is replaced by a Levalloiso-Mousterian industry. The first phase of the Last Glaciation still belongs to the Levalloiso-Mousterian. The upper Palaeolithic appears early in the interstadial $LGl_{1/2}$. Upper Palaeolithic survives the second phase of the Last Glaciation and is replaced by Mesolithic at a time after LGl_2 which, in Palestine, cannot be determined with accuracy.

In detail, however, differences between the Palestinian and European successions are apparent. The task of discussing these must on the whole be left to the typologists, though a few

implications of both the detailed relative, and the absolute chronology will be mentioned in the summary (p. 239), and in Chapter IX.

Egypt. The terraces of the River Nile and their Palaeolithic industries have been the subject of intensive study by Sandford and Arkell (1934, 1939). Recently, W. B. Wright (1939) has suggested a correlation of the terraces of the Nile, Thames and Somme and emphasized the resemblance of the three systems. Although the human industries appear in the same order in these areas and aggradation terraces were formed from time to time, the climatic conditions were utterly different, and the heights of the terraces agree less well than they seem to do at a first glance.

No direct observations on ancient sea-levels are available near the mouth of the Nile. The sea-levels into which the terraces ran have to be reconstructed. This was done by Sandford, in Sandford and Arkell (1934), and more recently by Ball (1939) with somewhat different results. Sandford's results may be summarized as follows (with Leakey's (1936) interpretation of the industries in angular brackets). (See page 231.)

This table gives on the left the heights above the Recent flood-plain of the Nile terraces, and on the right the shore-lines with which they have been correlated. Sandford based this correlation on the assumption that the terraces maintained their heights right down to the sea and that the mouth of the river did not shift. The human industries of the terraces make up the middle portion of the table. The Tyrrhenian would be associated with a series from primitive Chellian to early Acheulian, and with coarse Clactonian. This agrees only in part with European evidence, where the Chellian (Abbevillian [1]) is older. If one takes a broad view, the implements of the later terraces agree with finds in other regions, especially if Leakey's typological classification is adopted. The Clactonian and part of the Acheulian occur in the Penultimate Interglacial, typical and developed Levalloisian in the Last Interglacial, and the Levalloisian survives this interglacial. The Aterian (?) and the Sebilian cannot yet be dated here, but in part they are likely to correspond to the Last Glaciation.

J. Ball (1939) has again taken up the question of the sea-levels with which the terraces of the Nile were connected. He has based his work on that of Sandford and Arkell but, instead of assuming that the terraces were entirely parallel to the flood-plain, he calculated their gradients. These vary between 1 in 7,400 and 1 in 11,500. He also estimated the position of the coast-line during the various periods. No evidence being obtainable in the region of the delta, he re-

[1] 'Chellian' is retained for Egypt, since this term may or may not include the Lower Acheulian of Breuil. If it does, the discrepancy with Europe would disappear.

NILE TERRACES :—

Height above alluvium, metres	Industry	Sea-level possibly corresponding
220	—	—
195	—	—
140	—	—
115	—	—
90	—	100–90 metres Sicilian
60	—	60–55 metres, Milazzian
45	—	9 metres below Milazzian, subphase to Milazzian ?
30	Primitive Chellian, Chellian, Chellio-Acheulian or early Acheulian, coarse Clactonian	35–30 metres, Tyrrhenian
15	Developed Acheulian	20–18 metres, Monastirian
9	Acheulian probably derived [possibly late Acheulian; Huzayyin, 1941, p. 189]. Early Mousterian flakes and cores [typical Levalloisian]	20–18 metres, Monastirian
3–5 metres, upper Egypt	Typical Mousterian of Egypt [developed Levalloisian]	7.5 metres, Late Monastirian
7·5 metres, gravels, middle Egypt	In part contemporary with 3–5 metres terrace of upper Egypt, same industry but with later forms identical with those of the base of the upper Egyptian silts	7.5 metres, Late Monastirian
Base of silts, upper Egypt	Mousterian [Levalloisian]	—
Aggradation silts, upper Egypt	Final Mousterian [cf. Aterian], descending from it lower Sebilian (see Garrod, 1938, p. 17)	—
Degradation gravels of upper and middle Egypt, sub-alluvial in North	Middle and upper Sebilian [Mesolithic]	—
Accumulation	End of Palaeolithic [end of Mesolithic] Neolithic to Recent	—

constructed the coast-line, using the edge of the hills north of Cairo as a base. His results are as follows:

Period	Terrace, Industry	Sea-level at metres
Late Pliocene	140 metres Nile terrace	+154
Late Pliocene	115 metres Nile terrace	+129
Early Pleistocene	90 metres Nile terrace	+103 (+103)
Early Pleistocene	60 metres Nile terrace	+ 72
Early Pleistocene	45 metres Nile terrace	+ 57 (+60)
Early Palaeolithic	30 metres terrace, Chellian	+ 41 (+45)
Early Palaeolithic	15 metres terrace, Acheulian	+ 25 (+30)
Middle Palaeolithic	9 metres terrace, early Mousterian	+ 18 (+18)
Middle Palaeolithic	middle Mousterian	− 12
Middle Palaeolithic	late Mousterian	+ 16
Late Palaeolithic	early Sebilian	+ 13
Late Palaeolithic	middle Sebilian	+ 3
Late Palaeolithic	late Sebilian	− 43
Neolithic	early Neolithic	− 10
Present day		0

One notices that the calculated sea-levels are higher than the heights of the terraces above the alluvium of the river. The terrace with Chellian (30 metres above flood-plain) connects with a sea-level of 41 metres. This is rather high for the Tyrrhenian shore-line of 30–35 metres observed elsewhere, and closer to the post-Milazzian level of 45 metres, at which one would expect to find Chellian = Abbevillian (but see footnote (1), p. 233). The terrace with Acheulian (15 metres) runs into a 25 metre sea-level which might be Tyrrhenian.

Ball's figures, however, are extrapolated and therefore not very reliable. The table shows that some approach known levels of the Mediterranean closely (added in brackets), others less so. Ball's heights for the low-levels have to be regarded as a first approximation. Yet, on the whole, Ball's procedure appears to be sound. There is little doubt but that the shore-lines were higher above present sea-level than were the corresponding terraces above the present flood-plain of the Nile. The chief source of inaccuracy is the delta. At earlier periods it probably was smaller than now. At times, it may have been almost absent, at times it may have projected considerably, to be destroyed at some later period and to be built up

once more. A difference in height of several metres is involved in reconstructing former sea-levels with or without deltaic deposits, and this perhaps explains the deviation of some of Ball's figures from those found in other parts of the Mediterranean.

Thus the Nile does not yet provide conclusive evidence bearing on the Pleistocene sea-levels and the correlation of human industries with the shore-lines. The attempts which have been made are promising, and there is every chance that the Pleistocene and prehistoric chronology of Egypt will coalesce with that of other parts of the Mediterranean.[1]

Algeria. For the north coast of Africa, which is so prolific from the archaeologist's point of view, climatic evidence is as yet insufficient.[2]

The relation of early man to the Main Monastirian sea-level has been elucidated by Doumergue's papers (1922, 1934). At St. Roch-sur-Mer, Algiers, there is a sea-cave slightly above the present sea-level. It must have been formed during or after the 18 metres high level. It is filled with terrestrial deposits containing a Mousterian industry which, therefore, post-dates the 18 metres phase. Another Mousterian or Levalloisian site was described by Doumergue from Karouba. It lay on the 18 metres deposits with *Strombus*-fauna and confirmed the conclusion that at least part of the Mousterian or Levalloisian is later than this, the Main Monastirian, level. This agrees with observations made elsewhere.

E. WESTERN MEDITERRANEAN AND SPAIN

Gibraltar, Devils Tower. The famous rock-shelter of Devils Tower, Gibraltar, has not provided a climatic succession. An attempt to fit it into the general chronology, however, is worth while. The site was discovered by Breuil and excavated by Miss Garrod (1928). It yielded *Homo neanderthalensis* and a Mousterian industry, resting on a marine beach 8·5 metres above the present sea-level. The position renders any age earlier than Late Monastirian unlikely. Since the cave appears to have been entered by the waves of this phase of the Last Interglacial, the deposits containing evidence of

[1] A very comprehensive study of the north African Pleistocene and Palaeolithic by S. A. Huzayyin (1941) appeared after this chapter had been written. It was impossible to insert the numerous references which this work deserves, and the reader who requires more information should consult it. Huzayyin's book is largely a synthesis of all available evidence, and it develops a tentative chronology which is as consistent as possible with the known facts. In the present book, however, the evidence has been sifted according to its significance for the climatic chronology, and many interesting and potentially important sites have been excluded. Such sites are mentioned in abundance in Huzayyin (1941) from the whole of north Africa, and with their aid Huzayyin has been able to present a much more complete, though necessarily not final, chronology of the Palaeolithic of his region. See also Note (II), p. 389.

[2] See previous footnote.

early man can, at the earliest, date from the time of the recession of the sea from this high level to the low level of the first phase of the Last Glaciation.

The vertebrate fauna, determined by Miss Bate (1928) indicates a climate somewhat cooler and damper than the present and therefore supports the conclusion just arrived at, ibex being frequent, and the great auk and the alpine chough present. The Devils Tower deposit is thus best regarded as dating from the beginning of the first phase of the Last Glaciation. The Neanderthal skull and the accompanying Mousterian are, on this view, contemporary with the skull from the Monte Circeo in Italy (p. 220).

Olha, Basses-Pyrénées. The Pleistocene climatic fluctuations and their relation to the Palaeolithic industries in northern Spain is illustrated by the Castillo cave, near Villacariedo in the province of Santander, and on the French side of the western Pyrenees by the rock-shelter of Olha (Basses-Pyrénées).

As demonstrated by Obermaier (1924, 1935, 1937*a*) and A. C. Blanc (1937*d*), there is faunal evidence at Olha for a change from warm to cold conditions during the Mousterian, the lower Mousterian beds containing *Dicerorhinus merckii* and a deer (not reindeer), whilst the higher Mousterian Levels are accompanied by reindeer, woolly rhinoceros and mammoth. The climate of the higher Mousterian level, therefore, appears to have been fairly cold on the French side of the western Pyrenees.

Castillo cave, north Spain. In the Castillo cave, however, the faunal change is not the same. The sequence of deposits of this important locality is as follows (Obermaier 1924, pp. 161–6 ; Blanc 1937*d*, p. 11):

(Z) Recent detritus.

(Y) Stalagmitic deposit.

(X) Eneolithic industry.

(W) Azilian industry with flattened harpoons.

(V) Stalagmitic deposit.

(U) Late Magdalenian industry, including harpoons with a single row of barbs and perforated base. Fauna chiefly red deer. *Cyprina islandica.*

(T) Clay layer, almost sterile.

(S) Early Magdalenian. An enormous deposit of ashes, nearly six feet deep. Flint implements poor, but many artefacts in bone and horn. Human remains. Chief among the fauna red deer, also a few remains of reindeer.
Cyprina islandica.

(R) Clay layer, almost sterile.

(Q) Early Solutrian, with laurel leaf points without concave base. Fauna consisting chiefly of horse. A few remains of reindeer. *Cyprina islandica.*

(P) Clay layer, almost sterile.

(O) Late Aurignacian, with typical Gravette points. Fauna consisting chiefly of horse, with a few remains of reindeer.

(N) Clay layer, almost sterile.

(M) Late Aurignacian, a few industrial remains. Principal fauna, horse.

(L) Clay layer, almost sterile.

(K) Late Aurignacian, few industrial remains. Principal fauna, horse.

(I) Clay layer, almost sterile.

(H) Middle Aurignacian, keeled scrapers, and bone points with cleft base. Scattered human remains. Principal fauna, red deer and *Dicerorhinus merckii.*

(G) Stalagmitic deposit.

(F) Late Mousterian industry in stone, small but characteristic, including hand-points and scrapers. Many large implements in quartzite, serpentine, sandstone and limestone. Principal fauna, red deer, *D. merckii*, and *Elephas antiquus*.

(E) Clay layer, almost sterile.

(D) Late Mousterian industry with finely made small forms. Few large quartzite implements. Principal fauna, red deer and *D. merckii*.

(C) Stalagmitic deposit.

(B) Early Acheulian, with typical hand-axes, worked on both sides. Much worked limestone. Ochre. Principal fauna, red deer and *D. merckii*.

(A) Clay, with a few atypical implements and remains of hearth fires. Principal fauna, cave bear and, rarely, reindeer and marmot.

(—) Rock bottom of cave.

In this cave, a basal deposit with reindeer and marmot suggests a cold phase older than any so far considered, since it is covered by a stratum containing early Acheulian and since the remaining succession accounts for the three phases of the Last Glaciation. Layer (A), therefore, dates at least from the Penultimate Glaciation. Layer (B), containing the Acheulian, is associated with a forest fauna which, for northern Spain, suggests temperate, interglacial or interstadial conditions. Layer (C), a stalagmite, suggests a damp phase. After this, the succession can be fitted into the frame-work of the chronology of the upper Pleistocene.

In layers (D) to (F) (not considering the sterile horizons), a late Mousterian is associated with a forest fauna, from which cold elements are absent. A damp phase followed (layer (G)), evidenced by a stalagmite. Remembering that in other parts of southern Europe damp phases appear to represent the glacial phases of the north, it is conceivable that the stalagmite (G) is the equivalent of the cold Mousterian deposit at Olha and, thus, of the first phase of the Last

YEARS B.P.	EQUIVAL. PHASE IN TEMP. EU.	44°N. RIVIERA CLIMATE	44°N. RIVIERA INDUSTRIES	44°N. VERSILIA CLIMATE	44°N. VERSILIA IND.	43°N. CASTILLO CLIMATE	43°N. CASTILLO INDUSTRIES
	POST-GLACIAL		MESOLITHIC				MESOLITHIC
25000	LGI$_3$	HUMID (WEAK)	CF. MAGDALENIAN OR CAPSIAN	COOL-HUMID	COMPARE TEXT	HUMID	
	LGI $_{2/3}$		MICROLITHIC UPPER PALAEOLITHIC	MEDITERRAN.		[FOREST]	LATE MAGDALEN.
72000	LGI$_2$	COLD FOREST HUMID	GRIMALDIAN	COLD-CONTINENTAL COOL-HUMID		COLD-CONTINENTAL [STEPPE]	SOLUTRIAN GRAVETTIAN
	LGI $_{1/2}$	COOL (ABOVE?) -TEMPERATE	AURIGNACIAN MOUSTERIAN	MEDITERRAN.		[FOREST]	MIDDLE AURIGNACIAN
115000	LGI$_1$	HUMID	UPPER MOUSTERIAN	SEA-LEVEL AT -90 M.		HUMID	[COLD MOUSTERIAN AT OLHA]
	LIGI	TEMPERATE	MOUSTERIAN MOUSTERIOID +ACHEULIAN			[FOREST]	LATE MOUSTERIAN
187000	PGI$_2$	HUMID				HUMID	ACHEULIAN
	PGI $_{1/2}$	TEMPERATE	MOUSTERIOID				
230000	PGI$_1$	HUMID					
		TEMPERATE	CLACTONIAN				

FIG. 73.—Chronology of climatic phases a

42° N. PONTINE MARSHES CLIMATE	INDUSTRIES	40°N. ROMANELLI CLIMATE	INDUSTRIES	36° N. GIBRALTAR CLIMATE	INDUSTRIES	33°N. MOUNT CARMEL CLIMATE	INDUSTRIES
						DRY [STEPPE]	MESOLITHIC
SEA-LEVEL LOW							
	GRIMALDIAN [MOUST. SURV?]						
COLD-CONTINENTAL	"EARLY" AURIGNACIAN MOUSTERIAN	COOL-CONTINENTAL HUMID	GRIMALDIAN WITH CF. CAPSIAN			HUMID [FOREST]	ATLITIAN MIDDLE AURIGNACIAN
		MEDITERRAN.	GRIMALDIAN			DRY [STEPPE]	MIDDLE AURIGNACIAN CHATELPERRON
COOL-HUMID	MOUSTERIAN	HUMID		TEMPERATE FOREST	MOUSTERIAN	HUMID [FOREST]	UPPER LEVALLOISO-MOUSTERIAN
SEA WARMER THAN NOW		WARM 8M.-SEA-LEVEL	PRE-AURIGN.	SEA WARMER THAN NOW		DRY [STEPPE]	LOWER LEV.-MOUSTERIAN UPP. ACHEULIAN CF MICOQUIAN
						HUMID [FOREST]	UPPER ACHEULIAN
							TAYACIAN

nd Palaeolithic in the Mediterranean.

Glaciation. The absence of cold fauna from the Castillo cave may be explained either by assuming that it is accidental, no man or beast having lived in the cave during this cool phase, or by saying that here, south (more correctly west) of the great barrier of the Pyrenees, the cold fauna joined with a certain retardation, appearing only with the second phase of the Last Glaciation (A. C. Blanc, 1937*d*, p. 13). If this is correct, the first phase of the Last Glaciation would have been felt as a cold phase in southern France, and as a damp phase in northern Spain.

In layer (H) a temperate forest fauna is associated with middle Aurignacian. Being intercalated between deposits datable as LGl_1 and LGl_2, (H) represents the interstadial $LGl_{1/2}$.

With layer (K) a series of a different aspect begins. The predominant faunal element is the horse, which may be taken as signifying steppe environment. With it, the late Aurignacian (Gravettian) appears. The horse remains predominant through layers (M), (O), up to (Q), in which the Aurignacian is replaced by the Solutrian. In (O) and (Q), the reindeer appears, indicating that the steppe had become cold. A lowering of the temperature is further confirmed in (Q) by the presence of the marine shell *Cyprina islandica* which no longer lives on the coast of northern Spain. One thus gains the impression that the climate deteriorated from (H) to (Q), and that forests were replaced by cold steppe.

The following fossiliferous horizon, (S), is still cold, since reindeer is present, but forests must have begun to spread, since the red deer becomes the dominant species. Early Magdalenian replaces the Solutrian. *C. islandica* is still found.

In layer (U), the fauna indicates a further improvement of the climate, since the reindeer has disappeared. Red deer suggests forests. But the temperature had apparently not returned to the present-day level, since *C. islandica* still persisted in the neighbouring sea. This is the time of the late Magdalenian.

A stalagmitic deposit (V) covers immediately this late Magdalenian layer. It may be taken as evidence of a damp phase. Thereafter, the climate reverted to a less damp type, and the Mesolithic appeared (W). The three layers (U), (V) and (W) suggest that a damp phase occurred which was bordered by the late Magdalenian below and the Mesolithic above.

It is evident that one decidedly cold phase is contained in this succession, proved by (K) to (Q). It was followed by a moderate improvement of the climate, in (S) and (U), and by a decidedly damp phase. The Solutrian coincides with the maximum of the cold phase, the approach to which is marked by the late Aurignacian, and the decline of which by the Magdalenian. The damp phase is immediately followed by the Mesolithic. This succession resembles that of the second and third phases of the Last Glaciation of

central Europe so much that it may be regarded as probably correct.

In northern Spain, therefore, we observe a threefold division of the Last Glaciation, into a damp first phase, a dry and cold second phase, and a damp third phase. The ages of the Palaeolithic industries relative to the climatic phases are more or less the same as observed in central Europe.

F. CHRONOLOGY OF THE MEDITERRANEAN PALAEOLITHIC

Early phases up to the beginning of the Last Glaciation. The climatic phases and the succession of human industries during the (middle and) upper Pleistocene of the Mediterranean are summarized in the table, fig. 73.

Although the evidence for the correlation of pluvial phases with glacial phases is not yet as complete as one could wish, it must be admitted that the results so far achieved are consistent with one another and also with the astronomical theory. The tripartition of the Last Glaciation is evident in the north of the Mediterranean, but not so in the south, where the third phase appears to have been much weaker.

Archaeologically, the absolute chronology suggested by this correlation is of much less interest than the small differences in relative timing that become apparent. Here again, the available evidence is highly suggestive, but not yet complete enough to say that we are on perfectly safe ground.

During the Last Interglacial, we meet with Micoquian and lower Levalloiso-Mousterian in Palestine, and with Acheulian and a Mousterioid industry in the Riviera. This is quite consistent, and the *stratigraphical* evidence so far does not suggest any regional or chronological replacement of hand-axe by flake culture, or *vice versa*. Only towards the end of the interglacial, Mousterian, or a corresponding Levalloisian appears to prevail everywhere, the Acheulian having disappeared from the scene. This development agrees with that observed in temperate Europe.

The first phase of the Last Glaciation was witnessed by Mousterian and Levalloisian man in temperate Europe. In the Mediterranean, we find precisely the same, over more than ten degrees of latitude and over thirty degrees of longitude. *Homo neanderthalensis* is the only human species found.

Homo sapiens and upper Palaeolithic in the first interstadial of the Last Glaciation. With the beginning of the first interstadial of the Last Glaciation, regional differences become more apparent. They are significant because they are closely connected with the immigration of *H. sapiens* into Europe. In the preceding description of sites which are important from the standpoint of climatic and absolute chronology, I have as a rule adopted the nomenclature of

the industries used by the authors themselves. It is now necessary to raise this evidence on to the comprehensive plane provided by Miss Garrod's analysis of the upper Palaeolithic (1936, 1938). In doing so, it must be remembered that this important interstadial was by no means short, since 30,000 years may safely be assigned to it. This is a period long enough to permit of vast migrations and of repeated wholesale replacements of cultures over wide areas.

Typologically, three main groups of industries are now distinguished by Miss Garrod in the Mediterranean, which correspond roughly to the older divisions of lower, middle and upper Aurignacian:

Old Terminology	New Terminology
Upper Aurignacian	Grimaldian (partly contemporary with upper Gravettian) Upper Gravettian (including Font Robert) Lower Gravettian
Middle Aurignacian	Aurignacian s. str.
Lower Aurignacian	Chatelperronian

Strange to say, the Chatelperronian is much restricted in distribution, being almost confined to France and Palestine; it has been recorded from Poland (Breuil in Garrod, 1938, p. 20). Outside our area it occurs in East Africa. Unfortunately, the French Chatelperronian has not yet been fitted into the detailed climatic chronology, so that we are unable to say whether it belongs to the interstadial $LGl_{1/2}$, or is earlier. This is a question which urgently requires an answer, since the Palestinian Chatelperronian, which is less primitive than that from France, follows the pluvial of LGl_1 apparently without any delay (Wad F, fig. 72). It is conceivable, therefore, that the most primitive Chatelperronian is earlier than this, and contemporary with the first phase of the Last Glaciation, or even earlier still. There is one good reason which points to this possibility, namely the presence of a Chatelperronian element in the Micoquian of Palestine (Garrod and Bate, 1937, Tabun Ea and Eb), during the early half of the Last Interglacial. Furthermore, one might well explain the scarcity of Chatelperronian in Europe with the more general presence of Mousterian and Levalloisian during the late LIgl, and LGl_1. We would therefore have to visualize upper Palaeolithic man, or his ancestor (? a *sapiens*-type) present in some parts of the world during the Last Interglacial, spreading to Europe and occupying restricted areas during the first phase of the Last Glaciation while Neanderthal man was dominating the scene, but not succeeding in ousting the latter with his Mousterian or Mousterioid industry. As has been pointed out by A. C. Blanc (1938*b*, p. 12) and Coon (1939, p. 25; see Chapter IX, p. 298) the contemporaneity of the two types

of man is suggested by the mixture of their characters observed in the skeletons from the Skhul cave in Palestine.[1] The layers from which the skeletons came, were formed either at the end of the Last Interglacial, or during the first pluvial phase of the Last Glaciation. The existence of *H. sapiens* alongside of *H. neanderthalensis* for some time prior to the first interstadial of the Last Glaciation is, therefore, probable.

At the beginning of the interstadial in question, we thus find Mousterian surviving in certain areas, at least for a short while. This seems to apply to the Riviera, and Blanc has claimed it for the Pontine Marshes, though here this view is based on the occurrence of Mousterian in the following cold phase, *not* in deposits of the interstadial itself. Whether any Chatelperronian existed at this stage, we cannot say. However, the scarcity of sites with industries from the beginning of the interstadial creates the impression of a certain gap, as if the population of Europe and the northern Mediterranean was extremely thin. The Chatelperronians did not spread at the expense of the Mousterians.

Instead, we find that, when the mild conditions of the interstadial were properly established, a new immigration brought the middle Aurignacian to Europe (now 'Aurignacian' proper). Its typological relationship to the Chatelperronian is not clear (Garrod, 1938, p. 20). Chronologically, it occupies the second half of the interstadial $LGl_{1/2}$ in Palestine, whilst in western Europe it is found either in late deposits of the same phase, or in a chronologically uncertain position. It appears to have spread from the east (Garrod, 1938, fig. 6), but it also reached Italy.[2]

The cultural complexity of the first interstadial is further increased by the presence of upper Aurignacian (Grimaldian) in southern Italy. The 'Terra Rossa' of the Grotta Romanelli contains an industry which G. A. Blanc, and also Obermaier (1937), assign to the Grimaldian. Affinities to the Capsian of North Africa are noted as well. If these claims can be substantiated, the Grimaldian of the Terra Rossa of Romanelli, from the interstadial $LGl_{1/2}$, would be the earliest in Europe. The implications of such a date are considerable (see also p. 292), since it might suggest a southern route of immigration, and it indicates that part of the Capsian was contemporaneous with this interstadial.

Second and third phases of the Last Glaciation. Elsewhere, the upper Aurignacian, either in the form of the Gravettian, or the

[1] In fairness to the describers, Keith and McCown (1937), it should be said that they prefer to regard Mount Carmel man rather as a transitional type than a hybrid race.

[2] Blanc (1939*b*) described it from the Grotta del Fossèllone not far from the Pontine Marshes. Its chronological position is not certain, however, except that it post-dates the Last Interglacial and a Mousterian stratum from which it is separated by a sterile layer.

Grimaldian (chiefly in Italy), is characteristic of the second phase of the Last Glaciation.

Typical Gravettian comes from France, where its precise chronological position has not yet been studied. But judging by the fact that it immediately precedes the short-lived Solutrian, which in central Europe is confined to the maximum of LGl_2, the typical Gravettian presumably dates from the first half of this cold phase, though it might have continued on in areas where the Solutrian does not provide a datum line. In the northern Mediterranean, the Grimaldian largely replaces the Gravettian. It is typical of the cold-continental phase of LGl_2 in Italy (Romanelli, with distinct Capsian affinites, considered by A. C. Blanc as precocious Mesolithic features). A local survival of the Grimaldian into the interstadial $LGl_{2/3}$ is possible, though suggested only by the somewhat unsatisfactory evidence from the Versilia and the Pontine Marshes (p. 212, p. 217).

The problem of the local survival both of the Mousterian and of the Grimaldian is worthy of further investigation. A. C. Blanc (1938*b*, *c*) has developed a theory, according to which the replacement of the Mousterian by upper Palaeolithic was, in parts of Italy, spread over a much longer period than is here advocated, the last traces of the Mousterian disappearing only during the interstadial $LGl_{2/3}$.

Very naturally, the sequence of industries for the interstadial $LGl_{2/3}$ and the phase LGl_3 can be traced in the northern Mediterranean only, where distinguishable deposits have been found. Much remains to be investigated here. Fortunately, the sequence of the Riparo Mochi near Grimaldi, on which A. C. Blanc has published a preliminary report, promises to throw further light on this part of archaeological chronology. Here, the interstadial $LGl_{2/3}$ contains a microlithic variant of the upper Palaeolithic, and LGl_3 an industry reminiscent of Magdalenian or Capsian. Evidently, these industries require further and more detailed study.

The beginning of the Mesolithic which in temperate Europe can be dated as following the maximum of LGl_3, may have to be placed earlier in the south. This question remains entirely open, and any answer is rendered difficult by the practical impossibility of a sharp distinction between upper Palaeolithic and Mesolithic. Indisputably Mesolithic cultures, however, are present in the Riviera and northern Spain following the third phase of the Last Glaciation. This is in agreement with temperate Europe. Farther south, the stratigraphical position of the Mesolithic is uncertain. In Palestine, where no evidence for LGl_3 is available, 'the one quite definite gap' in the sequence of the Carmel caves exists between Wad C (Atlitian, upper Aurignacian) and Wad B (Natufian, Mesolithic) (Garrod, 1937, p. 117). This gap is filled by a peculiar microlithic industry which Turville-Petre found at el-Kebarah, and which Garrod calls Kebaran.

Even so, the age of the Palestinian Mesolithic, the highly-developed Natufian, remains uncertain. But it should not be assumed that the Mesolithic must be Postglacial everywhere.

CHAPTER VIII

CLIMATIC PHASES, EARLY MAN AND HUMAN INDUSTRIES IN AFRICA, ASIA, AUSTRALIA AND AMERICA

The extension of the detailed relative chronology, and of the absolute chronology based on the astronomical theory, to parts of the world other than the northern temperate zone and the Mediterranean encounters many difficulties. The basic obstacle is, of course, the scarcity of well-studied sections, the second, the difficulty of interpreting Pleistocene deposits correctly in climatic terms, the third, that of the differences of the faunas, and the fourth, that of interpreting changes in solar radiation in terms of climates in zones where neither modern meteorology nor geological evidence are as yet able to guide us to any great extent.

The present chapter, therefore, is bound to be no more than a preliminary survey of the situation. Nevertheless, it may be useful to point out promising localities; to review the successions of climatic phases which have been recognized, or suggested, for various parts of the earth; to relate those few discoveries which can be dated approximately; and to speculate on certain possibilities of extending the absolute chronology to other climatic zones.

In doing so, we shall first pass south through Africa, then proceed to Asia, to Australia and, finally to America.

A. THE SAHARAN DRY BELT

The dry belt which lies to the south of the Mediterranean zone and comprises the Sahara, the Arabian desert and corresponding countries farther east, is still influenced by the weather of the Mediterranean zone. The few sections which are known from this belt and provide information about the succession of climatic phases and of human industries are of particular importance as stepping stones from the Mediterranean to the tropical zone. One of these localities is the Fayum, but its Pleistocene succession is at the present a matter of controversy (Thompson, Gardner and Huzayyin, 1937, with bibliography), so that, for Africa, we have to confine ourselves to Kharga Oasis.

Kharga Oasis. Kharga lies in the Egyptian Desert, on 25 ½° N. lat. The Oasis contains a number of springs which, during periods of abundant flow produced a calcareous tufa. The tufas (travertines) alternate with phases of fluviatile erosion and aggrada-

tion. It is the merit of Miss Gardner (1932, 1935) and Miss Caton-Thompson (1932, also joint paper, 1932) to have established a sequence of climatic phases from these deposits, as follows, beginning with the earliest identifiable events:

(1) Deposition of tufa on plateaus: some rain.

(2) Great erosion: increased rainfall.

(3) Long period of breccia formation: little or no rain.

(4) Tufa, gravel and silt deposited on the breccia, more vegetation: some rain. Upper Acheulian.

(5) Intense erosion: maximum of moist conditions of prehistoric times. Acheulio-Levalloisian.

(6) Silt and gravel, followed by tufa: less rain.

(7) Erosion: more rain, second maximum on the rainfall curve.

(8) Silt and gravel, followed by tufa: less rain. Late middle Palaeolithic (pre-Sebilian).

(9) Erosion on smaller scale, followed by formation of 7 metre-terrace: slight humid oscillation followed by a drier phase, final conditions drier than in (8). Pre-Sebilian in the gravels, Aterian in the silt covering them.

(10) Erosion on still smaller scale, followed by formation of 5 metre-terrace: very slight humid oscillation followed by dry conditions leading up to the present day. Typologically correlated (though not on direct evidence) with the late upper Palaeolithic or Mesolithic (Capso-Tardenoisian).

The sequence provides evidence for five more or less damp phases separated by drier phases, namely (2), (5), (7), (9), (10). Of these, the last four form a group, separated from the first by a long period of dryness, (3). The damp phases (5), (7), (9), (10), decrease in intensity in this order, (5) being regarded as the maximum of moist conditions, and (10) being described as a decidedly weak phase. One is inclined to regard the long, dry period (3) as the representative of the Last Interglacial, the preceding moist phase, (2) as the equivalent of one of the earlier glacial phases, and (5) to (10) as the equivalent of the Last Glaciation. There is no geological proof for this correlation,[1] which is however, suggested (*a*) by the assumption

[1] For further detailed discussion, see Huzayyin (1941, p. 88 ff.). While the above summary was in the proof stage Miss G. Caton-Thompson kindly informed me that her forthcoming publication on Kharga Oasis embodies fresh evidence which increases the number of recognizable phases from (8) onwards. Furthermore, the industrial sequence is assuming a more complicated aspect which, in a much simplified form, may be summarized as follows:

Phase (8). Late Levalloisian, *not* Pre-Sebilian.
Phase (9). Levalloiso-Khargan, *not* Pre-Sebilian.
Phase (10). 'Khargan', i.e. former Pre-Sebilian, probably overlapping with an intrusive and late form of the Aterian.
Post-Phase (10). An intermediate site, typologically difficult, leading to a microlithic industry which is *not* Capso-Tardenoisian.

I am grateful to Miss Caton-Thompson for her permission to insert this information which may amplify the climatic interpretations here suggested.

that the Mediterranean pluvials will have made the climate of the Sahara damper than it is to-day, and (*b*) by the human industries which, taken as a whole, would in any part of the Mediterranean be taken as upper Pleistocene.

If this correlation can be substantiated, the Last Glaciation would, in this part of the Sahara (25° N.) be represented by four damp phases of decreasing intensity, instead of the three found in the Mediterranean. This curious feature finds some support in the radiation curve for 25° S., which shows four summer minima of decreasing intensity at 116,000, 94,000, 72,000 and 22,000 years B.P., that of 94,000 being one which is inconspicuous further north.

It is highly desirable that further detailed work in this area be carried out in order to test this tentative correlation of the Kharga sequence with the radiation curve, since here a chance is afforded to date both Miss Caton-Thompson's pre-Sebilian and the Aterian. The pre-Sebilian would have developed from the Levalloisian shortly before LGl_2, i.e. at the time, when in Europe the middle Palaeolithic was being replaced by upper Palaeolithic. It would have survived into LGl_2 and thereafter been replaced by Aterian, another derivative of the Levalloisian, showing abundant signs of connexions with upper Palaeolithic industries.

On the other hand, it must not be overlooked that the phases (9) and (10) may be regarded as very minor, Postglacial phases, phases (5) and (7) representing LGl_1 and LGl_2. In this case the pre-Sebilian would not have appeared until after LGl_2, and the Aterian would be Postglacial. This alternative would neglect the radiation curve and emphasize the distant effects of the ice-sheets of LGl_1 and LGl_2. Though it cannot be disproved, it appears to me the less likely.

Yemen and Hadhramaut. The expedition to Yemen (about 15° N. lat.) of the Egyptian University (Huzayyin, 1937; 1941, p. 125), detailed reports on which have not yet appeared, found evidence of two major pluvials of which the earlier one was more intense. The second pluvial can be subdivided into at least two subphases, possibly followed by a third weaker one. The first pluvial appears to be divisible also. Similar pluvials were found to have occurred in the Hadhramaut (Caton-Thompson and Gardner, 1938, 1939). Both these pluvials are contemporary with a Levalloisian variety of the Palaeolithic.

The climate of southwest Arabia, which lies on the southern edge of the dry belt, is influenced by the monsoon, and it is more likely that the pluvials observed under this latitude correspond to pluvials of the tropical zone. There is no evidence that the tropical pluvials were contemporary with those of the Mediterranean region, so that a correlation cannot even be attempted. But it is worth noting that the Saharan belt might have received more rain from the

north (during the glacial phases) as well as from the south (during phases of a more northerly position of the monsoon belt, see p. 267).

In addition to these Pleistocene fluctuations, Huzayyin (1935), found evidence of a minor damp phase of late Postglacial age, contemporary with an obsidian industry including most types of implements found in the final Palaeolithic and Neolithic of East Africa. It is associated with ruins of Sabaito-Himyarite culture which possibly lasted into the beginning of the Christian era. This phase is reminiscent of a slightly damper phase which concluded the Mesolithic in the Mount Carmel caves according to Miss Bate (1940), but Caton-Thompson and Gardner, though they found the same cultural association in the Hadhramaut, did not obtain proof of a damper climate. This very late, minor damp phase is still obscure in its character, whether it is wholly due to natural factors or partly connected with man's interference at the beginning of agriculture, remains to be seen. More evidence has been brought forward by French workers like Arambourg and Vaufrey from North Africa, and the covering stalagmites of some caves (Castillo, Grotta delle Capre) possibly belong to this category. Bate (1940) contains a summary of the observations made in Africa and Palestine in favour of such a late damp phase.

B. EAST AFRICA

Tropical Africa. In tropical East Africa, conspicuous work has been done on Pleistocene climatic phases and on human industries by a number of authors among whom Nilsson, Leakey, and Wayland are prominent. It is claimed that the climatic sequence, which can be read off in the numerous lake terraces of the great rift valleys, and in river terraces, comprises three major pluvials which can be subdivided further.

Kenya and Uganda. This sequence, originally conceived by Wayland in Uganda and by Nilsson in Kenya, was developed by

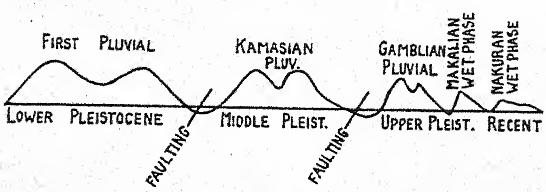


FIG. 74.—Fluctuations of rainfall intensity in Kenya, according to Leakey (1936).—From Zeuner (1944).

Leakey (1931, 1936). It distinguishes three major pluvials, First, or Kageran (a name suggested by Wayland), the second or Kamasian, the third or Gamblian, which is followed by two weaker damp phases called Makalian and Nakuran (fig. 74). In Kenya, each of the three

major pluvials is regarded by Leakey as composed of two phases. In Uganda, Wayland has subdivided the Kageran Pluvial (Pluvial I; 1932*a*, 1935, p. 70) on the evidence of terraces, and the Kamasian (Pluvial II) on the evidence of the M-horizon (see p. 253). For some time, Wayland (1939) regarded it as a matter of opinion whether the Gamblian was an independent pluvial or a subphase of the Kamasian, but on the whole, he (1934*b*, 1939) appears to be inclined to regard the sequences of major pluvials in Kenya and Uganda as the same, regardless of the question of subdivision. His publication on this subject and on the stone industries of Uganda, which is in preparation, will no doubt supply us with fresh evidence on this matter. Meanwhile, it appears that both in Kenya and Uganda, local workers distinguish three major pluvials.

This statement seems to be justified in spite of recent claims made by O'Brien (1939) that the succession of pluvial and dry phases in Uganda is of little significance. O'Brien co-operated with J. D. Solomon who holds that tectonic movements would explain the geological sequence of Uganda more satisfactorily than climatic oscillations. There is no doubt that tectonic movements played a prominent part in the Pleistocene history of East Africa, as shown particularly by the rift valleys which were formed in the course of the Pleistocene. But even so, O'Brien and Solomon admit repeatedly that climatic fluctuations did occur. The succession of pluvials with intrapluvials, and separated by interpluvials, however, appears at present to be somewhat uncertain. A description of the changing views of East African authors is found in O'Brien (1939, Chapter II).

The prehistoric industries, of which there are many, have been fitted by Leakey into his sequence of pluvials and interpluvials in the following manner. (See page 248.)

This table reproduces Leakey's views of 1936, and it should be read in conjunction with his chapters III and IV, which provide an excellent summary of the East African Stone Age. Mr. Wayland has also very kindly supplied me with an advance summary of his work in Uganda, from which it is apparent that no major divergences exist in the cultural sequences of that country and Kenya.

Only a few remarks on the archaeological sequence have to be made here, since the exact correlation of the sequence with those of other regions is not yet possible. The Kafuan of Wayland and Leakey is a very simple pebble industry which, in their view, is older than the entire hand-axe series. It is reminiscent of the Darmsdenian of Suffolk which, though it cannot be dated exactly, was regarded by Moir as Great Interglacial (Moir, 1935), but it is probable that, wherever pebbles are used as raw material, considerable convergence in the artefacts is bound to occur. The Kafuan is followed by the Oldowan (pre-Chellian of Wayland) which Leakey considers as a derivative of the Kafuan. The Oldowan in turn merges into the

	Pluvials	*East African Industries*				
Holocene	Nakuran Wet Phase	Gumban A	Gumban B	Njoroan	Tumbian	Wilton C
	Dry					
	Makalian Wet Phase End of Upper Pleistocene	Elmenteitan	Wilton A		Wilton B ↑ Upper Magosian	
Upper Pleistocene	Dry			Late Stillbay	Lower Magosian	
	Gamblian Pluvial	Upper Aurignacian *c* Upper Aurignacian *b* Upper Aurignacian *a* ↑ Lower Aurignacian		↖ Lower Stillbay ↗ Proto-Stillbay Developed Levalloisian		
	Dry	End of Middle Pleistocene (marked by great earth movements)				
Middle Pleistocene	Dry	Acheulian 6	Basal Aurignacian	Pseudo-Stillbay	Nanyukian	Levalloisian
	Kamasian Pluvial	Acheulian 5 Acheulian 4 Acheulian 3 Acheulian 2 Acheulian 1 Chellian 5 (or Transitional) Chellian 4 Chellian 3 Chellian 2 Chellian 1 Oldowan or pre-Chellian	↑ Proto-Aurignacian ?	↑ Sangoan Early Sangoan Traces of a flake culture	↖ Early Levalloisian ↗	
Lower Pleistocene	Dry ?	End of Lower Pleistocene				
	First Pluvial	Developed Kafuan Earliest Kafuan		Traces of a flake culture		

East African Chellian, and this into the Acheulian. This hand-axe series is roughly contemporary with the Kamasian Pluvial. There is a flake culture, however, the Sangoan discovered by Wayland, which is roughly contemporary with the hand-axe series, but van Riet Lowe (1937, p. 122) considers this as part and parcel of the hand-axe industry. Towards the end of the hand-axe period, late in the Kamasian, Levalloisian is held to appear.

The most remarkable feature of the East African sequence is the appearance of ' Proto-Aurignacian ' in the last stage of the Kamasian pluvial. After the dry phase which separates the Kamasian from the Gamblian pluvial, we find a ' lower Aurignacian ' co-existing with a developed Levalloisian (Leakey, 1931, 1936). This author is inclined to think that the Aurignacian sprang from the contact of the late Acheulian with the Levalloisian (1936, p. 185), but Garrod (1938, p. 19) finds it difficult to accept this view. It appears to be established, however, that the first typically upper Palaeolithic implements known so far, like blunted-back blades, made their appearance side by side with the latest Acheulian in East Africa.

By late Gamblian times, the ' Upper Kenya Aurignacian ' had developed into an industry which, as first pointed out by Vaufrey, and corroborated by Garrod (1938) is almost typical Capsian. In the meantime, the Levalloisian strain survived and developed into the Stillbay culture towards the end of the Gamblian.

It is impossible here to discuss the differences existing between Wayland and O'Brien with regard to the succession of industries in Uganda. It must suffice to say that they are in part differences in terminology and in part of a more serious nature, namely, stratigraphical. As an illustration, the position of the Kaiso Beds, the fauna of which was described by Hopwood (1926), may be mentioned. Wayland regarded them as interpluvial and later than the Kafuan industry, whilst Solomon and O'Brien classify them as preceding even the early Kafuan.

This very sketchy review of the sequence of climatic phases and of human industries in Kenya and Uganda shows that much work remains to be done. The enormous wealth of material which has been discovered indicates that the pioneer stage of research has been passed, and it will now be necessary to check the suggested sequences again and again with the aid of fresh sections. The possible lines of approach to a solution of the problem are illustrated in the following paragraphs by a number of instances.

Palaeontological divisions of East African Pleistocene. As in Europe, so in East Africa, the Pleistocene may be divided into three stages on faunal evidence. Much of the work on the mammalian fauna has been carried out by A. T. Hopwood (summary in Zeuner, 1944, p. 214). Yet it must be borne in mind that what are called

the Lower, Middle and Upper Pleistocene of Africa need not be, and probably are not, exactly contemporaneous with those in Europe. If it is permissible to judge by the amount of evolutionary change which occurred in the East African and the European faunas since the respective Lower Pleistocene deposits were laid down, one is inclined to admit that the chronological difference cannot be very great. Some Lower Pleistocene of East Africa may be contemporaneous with middle Pleistocene of Europe, or vice versa, but it is unlikely that the discrepancy would be as great as between Lower and Upper Pleistocene. This, at least, provides a rough chronological guide.

Kanam and Kanjera Beds, Kenya. In the gorges of the Homa Mountain, on the east side of Lake Victoria, a most instructive series of deposits is exposed. In it, implements have been found, and also remains of early man (Leakey, 1935), but the exact horizons of the latter are, unfortunately, not certain. The sequence has quite recently been re-described by Kent (1942*b*); it consists of—

(D) Fluviatile loams, &c. Upper Pleistocene ?

(C) Kanjera Beds, consisting of basal greenish tuffs and ash, middle group of clays with limestone and an upper transgressive bed of brown and greenish clays. The lower group has yielded a mammalian fauna of middle Pleistocene age, the middle group most probably contained the remains of *Homo* cf. *sapiens*, and the upper group covers the middle unconformably. Kent therefore came to the conclusion that the geological age of the remains of *Homo* is not certain. 'Human artifacts of Chellian type have been found *in situ* and on the surface of the beds, and pebble tools were found at an exposure a little to the south' (Kent, 1942*b*, p. 126). These pebble tools might, according to Kent, suggest a survival of the pebble industry into the Chellian. It would be most desirable to obtain evidence for the precise age both of the skull fragments and of the implements, in view of the possible association of *Homo* cf. *sapiens* with a 'Chellian' industry, but neither Leakey, nor Kent, nor any of the many other workers who studied the area (Boswell, Wayland, &c.) has succeeded in doing so.

(B) Rawe Beds, brown and yellowish laminated clays with sandstone bands. Lake deposits, with evidence of repeated drying up, in the form of pseudomorphs of a soda mineral, gaylussite. Climate apparently semi-arid, lamination indicating seasonal variation. Rich fauna of lower Pleistocene type.

(A) Kanam Beds, beds of light brown clay and fine volcanic tuffs, often grey-green and laminated. Some gravel deposits suggesting beaches. Fauna, determined (as that of the other beds) by Hopwood, of Lower Pleistocene type. Implements of pebble type (Oldowan of Leakey). A small fragment of a human lower jaw, *Homo* cf. *sapiens*, is believed to have come from these beds,

but its exact position could not be ascertained (Leakey, 1935, 1936*a*, *b*; Boswell, 1935; Kent, 1942*b*).

In this series, the Rawe Beds are regarded as evidence of a dry phase (interpluvial) intercalated between two more rainy phases of climate. On palaeontological evidence it can be correlated with the Kaiso Bone Beds of Uganda (early middle Pleistocene according to Wayland). For the time being, this important series tells us at least that the change from pebble culture to Chellian, or as van Riet Lowe (1937) prefers to call it, Stellenbosch I, was approximately simultaneous with the faunal change from Lower to Middle Pleistocene (African divisions).

Terraces of Kagera River, Uganda. Wayland (1935) distinguishes four terraces and a peneplain in the valley of the Kagera River, Uganda, which flows into Lake Victoria (fig. 75). This valley is important because here human industries occur abundantly in

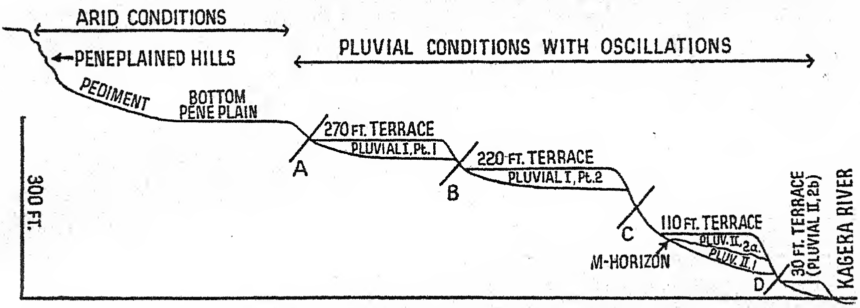


FIG. 75.—Diagrammatic section of the terraces of the Kagera River, Uganda.—After Wayland (1935, fig. 11). Modified, but with Wayland's interpretation. A. Beginning of pluvial conditions (widespread fluviatile erosion rendered possible by the existence of the Western Rift Valley towards which the rejuvenated rivers flowed.—B. Earth-movement and minor climatic oscillation.—C. Interpluvial conditions and earth-movement.—D. Earth-movement.

stratified deposits. Wayland interprets this sequence as follows. After a period of peneplanation in an arid climate, the 270 and 220-foot terraces were formed during two phases of the First Pluvial (which he suggests to call Kageran). A major period of erosion separates them from the 110-foot terrace of the Kamasian pluvial, and a 30-foot terrace which Wayland regards as a subphase of the Kamasian and which perhaps represents Leakey's Gamblian. This sequence is reproduced here as a general guide. It will be seen that earth movements connected with the formation of the great rift valleys interfered with the climatic succession, and that Wayland regards every terrace aggradation as evidence for a wet phase of climate.

On the other hand, Solomon (in O'Brien, 1939, fig. 4) distinguishes the same levels, but is not satisfied with the evidence of pluvial

conditions during the formation of these aggradations and comes to the conclusion 'that the Pluvial Hypothesis rests on very slender foundations' and he 'is inclined to discard it completely as a basis for the classification of the African Quaternary' (Solomon, in O'Brien, 1939, p. 41). The real difficulty appears to me to be that the conditions of formation of certain kinds of sediments, such as boulder beds, gravels and fine-grained river deposits in a tropical climate have not yet been studied. Boulder beds and coarse gravels are usually taken as evidence of a wet climate though, in reality, they need not mean more than occasional torrential floods. Such floods, however, are known to occur in various types of climate, including the semi-arid one. The problem of the rhythm of aggradation and erosion in tropical climates cannot be discussed here; it needs thorough investigation on the spot, where, however, it will be necessary to discriminate between the rhythm caused by tectonic movements and that due to climatic oscillations. A further complication which must not be overlooked is the one we are familiar with from European rivers, that the upper courses might well obey a rhythm of aggradation and erosion which is the reverse of that found further downstream near the base-level.

In spite of these difficulties, the terraces of the Kagera valley provide an important sequence of events, into which some of the human industries can be fitted. While the 'Kageran' levels contain the Kafuan pebble industry in several stages, the Kamasian sequence of the 100-foot terrace covers the Oldowan, Acheulian and Levalloisian. The 30-foot terrace has yielded only derived material.

Section of the Kagera 100-foot Terrace. The difficulties of interpretation of the terraces cannot entirely obscure the fact that there is some evidence for climatic fluctuations, and though the intensity of the pluvials may perhaps be disputed, Solomon, Wayland and others agree that arid, or semi-arid, phases occurred. The best evidence is provided by the M-horizon of the 100-foot terrace of the Kagera valley.

A section from the junction of the Orichinga valley with the Kagera valley (100-foot terrace) is the following (from Solomon, in O'Brien, 1939, p. 32):

(9) Grey and white clays and silts, *c.* 6 feet. Swamp deposits.

(8) Impersistent thin sandy layer with rubble (O-horizon); sometimes apparently represented by a reddening in the clays. ?Land-surface. No definite tools.

(7) Grey and white clays and silts, *c.* 15 feet. Typical swamp deposit. Few scattered implements.

(6) Sandy bed with rubble, sometimes implementiferous (N-horizon), 1–2 feet. Not indurated. ?Dry period. Proto-Tumbian and Levalloisian implements.

(–) Erosional unconformity.

(5) Pale silts with sandy layers, *c.* 4 feet. Swamp deposit.

(4) False-bedded sands with implementiferous horizons (Levalloisian), *c.* 15 feet.

(3) Hard, indurated implementiferous rubble (M-horizon), *c.* 1 foot. Lower or middle Acheulian industry. Dry phase.[1]

(–) Erosional unconformity teste Wayland (1935).

(2) Sands and clays, *c.* 50 feet. Lacustrine or swamp deposits.

(1) Boulder Bed, *c.* 2 feet, possibly of a torrential phase.

To a reader who is not involved in the controversy between O'Brien and Solomon and Wayland, this sequence appears to record repeated oscillations of the level of Lake Victoria and with it, the filling with lake and swamp deposits, and erosion, of the lower course of the Kagera River. Thus, the boulder bed (1) and the fossil granite cascades found at the bottom of this series at the Hydro-electric Station near Kikagati (O'Brien, 1939, pl. III, fig. 1) suggest erosion down to a low lake-level,[2] followed by deposition of 'swamp deposits' (2), while the lake-level rose. Then the lake sank again (M-horizon), rose (5), sank (erosional unconformity and N-horizon), rose (7), sank or was stable (O-horizon), rose (9), and finally sank to a level more than 60 feet down, where the formation of a later series was initiated. Four phases of high lake-level, each of which appears to have been higher than the preceding, are recognizable. Only one of the interphases, the M-horizon, has so far received close attention. Before we turn to the discussion of this interesting horizon, let us remember, that the evidence is, on the whole, accepted by all concerned as an indication of rise and fall of the lake-level. Wayland considers this oscillation as climatic, but Solomon and O'Brien think it is the result of tectonic tilting. The fourfold repetition of the process suggested by the Orichinga section is certainly more readily explained by a fluctuation of the rainfall which made the lake rise and fall, than by an oscillating tectonic movement which would have had to be reversed four times. The climatic case is especially strengthened by the arid character of the rubble phases.

The M-horizon. The M-horizon is by all investigators considered to have been formed in a dry climate. Wayland (1935) says that a fall in the lake-level resulted in 'exposure and denudation of some (but not all) sediments of immediately pre-M-horizon date, and thus provided new land surfaces upon which early man lived, . . . while weathering resulted in ferruginization, so that to-day we have a red or ochreous, and in some places a decidedly hard, stony band packed with tools, cores and flakes'. O'Brien (1939, pp. 296–307) differs

[1] For rubble formation in a dry climate, see O'Brien (1939, p. 97). 'Rubble' is angular rock-waste.

[2] This was conceivably the phase of the steep, ungraded river following the subsidence of the lake-basin owing to tectonic movements.

from this view only in the suggestion that the reddening is a posthumous phenomenon, due to infiltration after the M-horizon had been buried, and he strengthens his case by quoting a locality where the reddening extends into the overlying deposit. O'Brien further subdivides the M-horizon into a basal, gravelly facies (A) and a later, rubble facies (B), only the latter being indicative of dry conditions when river activity had ceased or was reduced to a minimum.[1]

The implements of the M-horizon and of the subsequent phases of the Kamasian or 100-foot terrace are of the greatest interest, since they provide a stratigraphical succession for the cultures of the middle Pleistocene. The facies (A) of the M-horizon contains, according to O'Brien, upper Oldowan mixed with an early-middle Acheulian, and M-horizon (B) a developed middle Acheulian. Wayland (1935) considers the Oldowan elements as derived and calls the remaining assemblage Chellio-Acheulian, whilst Leakey (1936) and van Riet Lowe regard it as African Acheulian I. The latter author (1937, p. 122) goes further, comparing the tools with those from South Africa. He finds that the M-horizon implements are more advanced than Stellenbosch II, but less varied and refined than Stellenbosch III. Considering how difficult it is to classify Acheulian even in Europe, we are satisfied to gather that the M-horizon contains an early or middle Acheulian, but no late Acheulian.

In the river and swamp deposits laid down on the M-horizon when the lake rose again, Levalloisian is found. The incoming of this flake culture at this moment is a remarkable parallel to Europe, where the Levalloisian appeared when the Acheulian had reached the 'middle' stage.

The Kagera valley is bound to play a great part in the chronology of the East African Pleistocene. Irrespective of any suggested system of pluvials, we can say that the available evidence suggests repeated oscillations of the lake level during the middle Pleistocene, which are more easily understood if taken as due to changes in the amount of rainfall. In the Kagera valley, four damp phases would be in evidence during the middle Pleistocene (100-foot terrace), separated by dry phases of which the first was the most conspicuous.

The evidence from Kanam and Kanjera, on the other side of Lake Victoria, appears to indicate that the sequence of the 100-foot terrace of the Kagera valley was preceded by another dry phase (Rawe Beds), possibly with a gap.

Tanganyika. Olduvai. The classic site of Tanganyika is Olduvai, or Oldoway, a gorge running into the (now dry) Balbal depression north of Lake Eyasi. It was made famous by a skeleton of *Homo sapiens* which Reck (1914) believed to come from a relatively early

[1] Solomon (in O'Brien, 1939, p. 33) does not recognize these two levels.

horizon (II), but which is now regarded as an interment dug into this layer. This sequence has been studied repeatedly (summary in Leakey, 1936, with references) and the fauna is being described in a series of monographs; see, for instance, Hopwood (1933). Most recently, Kent (1941, 1942*a*) has placed the Olduvai sequence into a larger frame by comparing it with other Pleistocene deposits of the Tanganyika rift valley. The sections may be summarized as follows:

(V) Terrestrial, often loess-like, deposits covered by steppe-lime, a soil of concretionary nature. 'Mousterian' and Aurignacian industries.

(—) Unconformity.

(IV) Volcanic tuff, deposited or re-deposited in water. Acheulian implements.

(III) About 15 metres of red, tough rock, containing lenses of pebbles. Deposited in water. Held by Wayland (1935, p. 73) to be the reddened upper portion of Bed II, and comparable with the M-horizon of Uganda. Implements of late Chellian and primitive Acheulian type.

(II) Volcanic material, similar to (IV). Implements of Chellian technique.

(I) Very thick terrestrial deposit, of numerous layers of volcanic tuff. Oldowan pebble industry.

The lake deposits (II) to (IV) are considered to have been laid down during a major pluvial. On faunal evidence, they are middle Pleistocene, and on this they are comparable with the Kamasian of Kenya and Uganda.

Now it is most noteworthy that Wayland thinks that (III) corresponds to the M-horizon and indicates a dry oscillation. This view is corroborated by evidence from Lake Manyara, some 50 miles east of Lake Eyasi (Kent, 1942*a*). Archaeologically, too, Olduvai Bed III agrees with the M-Horizon. Its industry is Acheulian I according to Leakey, which van Riet Lowe considers as closely related to the South African Stellenbosch II/III.

Again, O'Brien puts forward a somewhat different interpretation, prompted chiefly by the typological argument that the industry of the M-horizon is middle Acheulian. He therefore correlates the M-horizon with Bed IV (1939, p. 302, etc.) and considers the reddening of Bed III as posthumous, as in the case of the M-horizon. But he does not object to assigning Bed III to a phase of lake-recession, presumably with a drier climate. Thus it appears that at least one dry oscillation interrupted the middle Pleistocene of Tanganyika also.

East Africa, summary. Let us now try to sum up what appears to be well established in the East African climatic and archaeological chronology. Climatically, it is certain that the lakes stood at

certain times much higher than they do at present, and at others relatively lower. Earth movements are bound to have played a part in determining these levels, but some of the evidence is difficult to understand without the assumption of climatic fluctuations. Whether the 'wet' phases connoted a general climate wetter than the present is not clear; there is no need to assume a catastrophic character of the 'pluvials' (Wayland, 1934, p. 348; Solomon and O'Brien, 1939). On the other hand, the dry phases need not have been more arid than the climate now prevailing locally in some parts of the rift valley (Kent, 1942*a*).

The succession of pluvials and interpluvials, which at one time looked impressive and well established, is no longer to be regarded as the last word. It is not certain whether there were three or more pluvial phases, and whether they were subdivided or not. All this has still to be established (or disproved) on conclusive evidence. The multiplicity of the oscillations of the climate, however, is highly probable.

The terms used for the pluvials have assumed a predominately stratigraphical significance, quite apart from the pluvial problem, the First Pluvial or Kageran being roughly the equivalent of the lower Pleistocene, the Kamasian of the middle, and the Gamblian of the upper. In this sense, they are likely to continue in use.

The succession of industries is in many respects similar to that of South Africa, and in spite of many differences it resembles, in the chief trend, that of Europe also: After some primitive stages a hand-axe culture develops from an Abbevillian to an Acheulian stage, accompanied by flake industries, the Levallosian technique appears during the Middle Acheulian, and the Upper Palaeolithic gains the ascendancy still later (though it seems to appear rather earlier than in Europe, p. 289). The Kamasian is the period of the hand-axe series, and the M-horizon, or its equivalent, is associated with the African Lower or Middle Acheulian.

C. SOUTH AFRICA

Rhodesia. On our way from the tropical zone of East Africa to the southern dry belt of South Africa, we pass through Rhodesia, where valuable archaeological work has been done, notably by Neville Jones (1926) and Armstrong. The Bambata Cave, for instance, has suggested the co-existence, or alternation, of Levalloisian and Aurignacian industries. But except for one locality, the Victoria Falls, the climatic sequences have not yet been worked out sufficiently to be of importance for our purpose. Readers will find a useful summary of Rhodesian Stone Age in Leakey (1936, Chapter VII).

Victoria Falls. At the Victoria Falls, the retrogressive cutting of the gorges is the most conspicuous phenomenon. As it proceeds,

successive sections of the upstream, high-level, bed of the river are laid dry. These high-level river deposits have provided a succession of human industries which were first fitted into the sequence of geological events by Armstrong, Jones and Maufe (1936). Cooke and Clark (1939) reinvestigated the area and came to somewhat different results, which they tabulated as shown in fig. 76.

South Africa. In South Africa, research both in Stone Age archaeology and Pleistocene climate is more advanced than in any other part of Africa (with the exception of Egypt). An additional advantage is that, here, we have left the tropical zone and have entered the southern dry belt, where the climate is less complex from a theoretical point of view. The area which has been studied most thoroughly is the Vaal River Basin (Söhnge, Visser and van Riet Lowe, 1937).

Since the numerous raised beaches of South Africa (see, for instance, Goodwin, 1933; Goodwin and Malan, 1935; Haughton, 1932) have as yet not yielded a sufficient number of sites upon which to build an archaeological chronology (summary, Cooke, 1941), whereas the Vaal River has done so, we shall confine our attention to the latter, and also omit the many sites which, though of great typological interest, cannot be dated geologically. Cooke's survey of the Quaternary in South Africa (1941) gives a more complete picture of the archaeological chronology, and fossil man has been reviewed recently by Dart (1940).

Vaal River. The climatic rhythm of erosion and accumulation of the Vaal, a river far removed from the fluctuations of the sea-levels, has been described by Söhnge and Visser (1937). Starting from the present-day, semi-arid, conditions in which the river deposits during the dry season and erodes during the wet (Söhnge and Visser, 1937, p. 49), one finds that,

(*a*) an increase of precipitation would lead to increased erosion (though, in the Pleistocene the climate has never been sufficiently wet to be called humid);

(*b*) a subsequent decrease to the deposition of gravel;

(*c*) a further decrease to the deposition of sand;

(*d*) a yet greater decrease to the deposition of eolian sands, and reddening and calcification of existing deposits.

Great falls in the Orange river, of which the Vaal is a tributary, have prevented low sea-level knickpoints from migrating upstream, so that the total effect of climatic erosion is small, and the terraces are low. Smaller rock barriers cross the river at a number of points and divide it into compartments each with its local base-level at the lip of the barrier below it. Consequently, the heights of the terraces of the different 'compartments' are not directly comparable. Tectonic movements also appear to have interfered, most probably between the periods of the Older Gravels and the Younger Gravels

(du Toit, 1933). The climatic cycle described has been confirmed for the three Younger Gravels only. The Older Gravels are merely remnants of aggradations to which the cycle theory is applied in a tentative manner. The Youngest Gravels and the Schoolplaats Phase are the products of weaker climatic oscillations.

The succession is most complete in the area of Windsorton and Barkly West near Kimberley, where all levels down to the Youngest Gravels are recognizable (pl. XVIII, fig. B). Much additional evidence comes from Taungs, on the Harts River, 50 miles north of Windsorton, and from Fauresmith near the Riet River, 90 miles to the south. Other important localities lie near Vereeniging, 250 miles east of Windsorton, where the Klip River joins the Vaal (pl. XVIII, fig. A). The succession is best based on the sections at Windsorton, supplemented to some extent by other localities. It may be summarized as follows (see also Note (3), p. 387):

(A) Peneplanation of Vaal River and formation of lower barrier at Barkly West. Climate humid (?). (Söhnge and Visser, 1937.)

(B) Formation of some very high terraces.

(C) Third Older, or Potato, Gravel Terrace, 200 feet above river. (Breuil, 1943*b*). Climate semi-humid to semi-arid.

(D) Second Older, or Potato, Gravel Terrace, 150 feet above river (Breuil, 1943*b*). Climate presumably, after a dry oscillation, again semi-humid to semi-arid.

(E) First Older, or Potato, Gravel Terrace, 60 to 80 feet above river (Breuil, 1943*b*). Climate as in (D). Breuil found implements *in* the three Older Gravels at Windsorton [1]). They comprise many pebble tools and few flakes, far more primitive than the Stellenbosch culture. On approaching the lowest level of the Older Gravels, bigger and clumsier flakes are more frequent and associated with small prototypes of bifaced pebble-tools and archaic hand-axes. At Vereeniging, a similarly primitive industry has been found in the 100 feet Terrace which probably corresponds to one of the Older Gravels of the Windsorton area (Amcor Factory site, Vereeniging, Breuil, 1943*b*).

At Vereeniging, the lowest aggradation of the Older Gravels lies on the 50-foot Terrace (Breuil, 1943*a*; Söhnge and Visser, 1937, p. 38) and contains tools of Stellenbosch I type in an unrolled condition (pl. XVIII, fig. A). This site was discovered by van Riet Lowe in 1920; it has now attained importance, since it shows that the 'Clacto-Abbevillian' industry (Riet Lowe, 1937, p. 78; Breuil, 1943*a*) usually called Stellenbosch I was established during the phase of pebble deposition of the lowest known Older Gravels of the Vaal River.

[1] The pebble industry from Amandelhoogte, Windsorton, described by van Riet Lowe (1937, pp. 75, 99, pls. 8–9), found *on* the Older Gravel at 80–100 ft., covered by fossil eolian sand, is now likely to belong to this terrace, since the latest Older Gravels at Vereeniging contain already a Stellenbosch I.

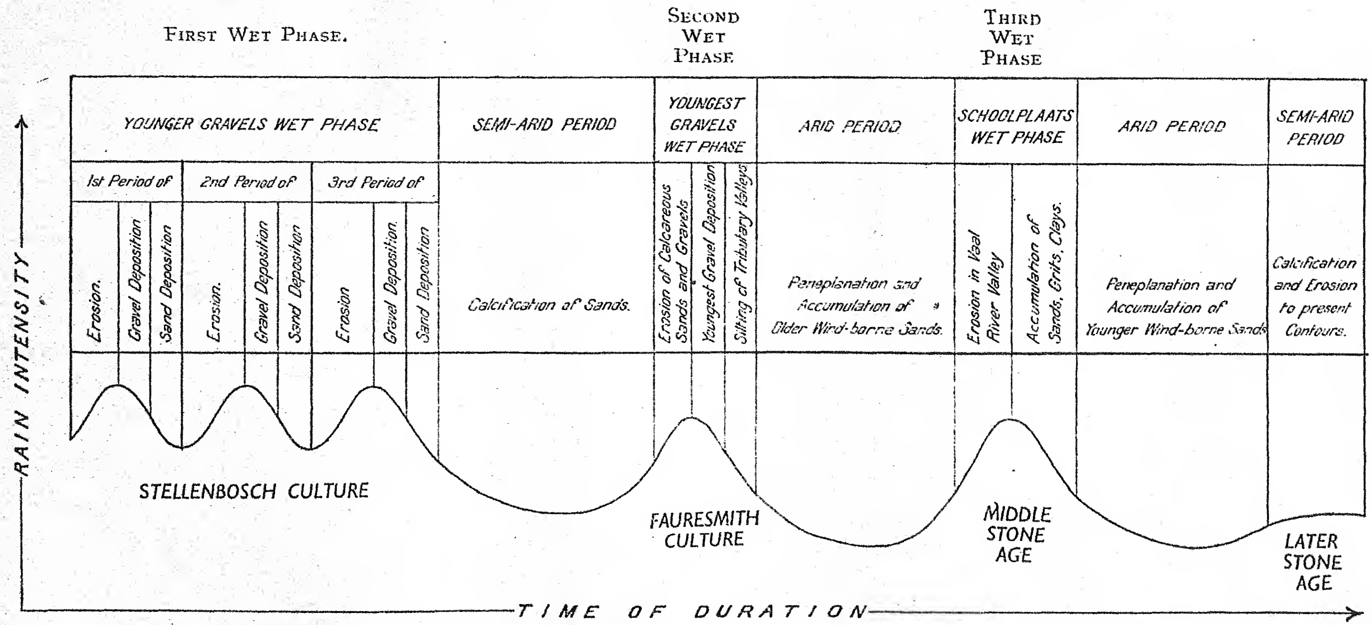


FIG. 77.—Climatogram for South Africa, from the Younger Gravels Phases onwards. From Söhnge, Visser and van Riet Lowe (1937, fig. 10).—Reproduced with permission.

(F) Accumulation of red eolian sand on Older Gravels. Climate (?) arid (Söhnge and Visser, 1937).

(G) Cutting and subsequent aggradation of Younger Gravels Terrace I, bench about 40 feet above river. Climate passing through a damp cycle, but becoming dry again. First Period of the so-called First Wet Phase of Söhnge, Visser and van Riet Lowe, 1937 (see fig. 77; pl. XIX, fig. A).

Industry, Stellenbosch I (van Riet Lowe, 1937, p. 77), a Clacto-Abbevillian with Abbevillian type hand-axes on cores or flakes (Clacton technique) and cleavers (rare) on flakes (Clacton type) (van Riet Lowe, 1937, p. 111). But (probably long) before the aggradation of Younger Gravels II began, Stellenbosch II (and later stages) had made its appearance (van Riet Lowe, 1937, p. 79). This stage marks the beginning of the Acheulian in South Africa; it is described as 'early to middle Acheul hand-axes on cores or flakes and cleavers on flakes derived in Tachengit and Clacton fashion' (van Riet Lowe, 1937, p. 111).

(H) Cutting and subsequent aggradation of Younger Gravels Terrace II, bench about 25 feet above river. Climate passing through a damp cycle, but becoming dry again. Second period of the so-called First Wet Phase.

Industry of the upper Stellenbosch type (Stellenbosch III–V, van Riet Lowe, 1937, p. 80, p. 128),[1] an advanced Acheulian, occasionally with S-twist and Micoque types, hand-axes and flakes struck from prepared proto-Levallois (Victoria West) cores (van Riet Lowe, 1937, p. 110; this book, pl. XIX, fig. B).

(I) Cutting of bench below present river level, to about —10 feet and subsequent aggradation of Younger Gravels Terrace III, (Söhnge and Visser, 1937, p. 45). Climate passing through a damp cycle, but becoming dry again. Third period of the so-called First Wet Phase.

Industry advanced Stellenbosch (van Riet Lowe, 1937, p. 87).

(J) Calcification of sand on Younger Gravels. Climate semi-arid. Cultural hiatus.

(K) Erosion and denudation of the sands (Vaal River) and formation of Youngest Gravels, preserved chiefly in tributary valleys (Riet River, Harts River, &c.), also at Riverview Estates, Windsorton (Söhnge and Visser, 1937, p. 47). Climate damp, 'Second Wet Phase', becoming semi-arid while tributary valleys are silted up.

Industry Fauresmith I, found on the denuded surface of the sands of the Younger Gravel phases, and in the Youngest Gravels. The Fauresmith I is an industry with Levallois technique used for the production of mostly small cleavers, scrapers and points. Small

[1] In some localities sands of Younger Gravels Phase III appear to overlie gravels of Phase II (Söhnge, Visser and van Riet Lowe, 1937, pp. 127–8).

evolved Acheul and Micoque type hand-axes. Crude gravers (van Riet Lowe, 1937, p. 110).

Later than the Second Wet Phase, but earlier than (L), is the Fauresmith II, which occurs *on* the deposits of the Youngest Gravels Phase. It is more finished than Fauresmith I and contains small, neat and beautifully trimmed hand-axes in association with an advanced Levallois technique (van Riet Lowe, 1937, p. 113).

(L) Accumulation of wind-borne sand. Arid climate.

(M) Erosion in Vaal River valley, followed by accumulation of gravel, grit, sand and clay. Climate ' damp ', ' Third Wet Phase '. Called *Schoolplaats Phase* after the typical locality, but numerous other sections exist, including the Riverview Estates at Windsorton.

Industry South African Middle Stone Age, a development from the Fauresmith with its Levallois technique; in its early phases it may be called South African Mousterian (van Riet Lowe, 1937, p. 113). The implements occur in the deposits of this phase (Söhnge and Visser, 1937, p. 49).

(N) Denudation and further accumulation of wind-borne sands. Climate arid. Middle Stone Age found beneath these sands, while later Stone Age occurs in its uppermost layers and on the surface (Söhnge and Visser, 1937, p. 49).

The succession of the various stages of the Middle Stone Age is not yet clear, except perhaps that the Stillbay and Mossel Bay varieties range late in the sequence. Van Riet Lowe emphasizes the difficulty of studying the stratigraphy of a culture which is confined to the surface and the uppermost few feet of the deposits.

After the arid phase (N), or towards its end, the later Stone Age appears.

(O) Calcification of sands and erosion to present contours. Climate semi-arid. Establishment of Recent conditions.

The later Stone Age is represented by the Smithfield Culture which van Riet Lowe divides into six stages (1937, p. 95). Divisions I to V are comparable with the Capsian, Aurignacian and Tardenoisian of Europe and North Africa, while Division VI is more closely related to the Tardenoisian plus certain north African Neolithic elements (*l.c.*, p. 98). The Wilton Culture, which has its European parallel in the Tardenoisian type of microlithic industries, is abundant also. Both Wilton and Smithfield cultures survived into modern times; they were probably practised by the Bushmen and other natives prior to the European expansion.[1]

South Africa, summary. The succession which has just been described comprises five damp phases since the beginning of the

[1] My friend, Mr. Day Kimball, has pointed out to me that, according to Brown (1887, p. 156, pl. V, fig. 8), modern Bushmen appear to have made and used hand-axes of the Stellenbosch type.

Younger Gravel times, and possibly several more preceding ones. There is also evidence for arid conditions (wind-blown, 'Kalahari' sand) prior to the Younger Gravels phase, prior to the Third Wet Phase, and prior to Recent times (fig. 77).

In this succession the phase of the Younger Gravels is the most conspicuous; it indicates a succession of damp subphases of which three have been distinguished. When reading the report of Söhnge, Visser and van Riet Lowe, however, one gains the impression that the distinction of these three subphases is by no means easy, and that there are possibly more than three benches in the Windsorton area between 40 feet and −10 feet. If the number of subphases of the Younger Gravels had to be increased, the stratigraphical succession might become more complicated, but the distinctive character of the Younger phase as a whole would be maintained.

Following the Younger Gravels Phase the climate was, broadly speaking, drier. Two 'damp' and two dry phases are recorded, but the damp phases are not evidenced by gravel aggradations of the type of the Younger Gravels, and sand and grit predominate. This suggests that both the Youngest Gravels and Schoolplaats phases were rather weak.

Preceding the Younger Gravels, the climate was arid for some time. This dry phase separates the Older Gravels from the Younger.

The Older Gravels cannot be directly compared with the Younger Gravels. They belong to terraces which cover a much wider range of altitude above the river. If we consider only the levels in which human implements have been found, between about 200 and 60 feet at Windsorton, and if we make the assumption (which need not be correct) that the height above the river (as indicating the amount of erosion), is an approximate measure of relative age, the period of the Older Gravels would appear to have been about three or four times as long as that of the Younger Gravels.

Furthermore, the Older Gravels are shallower than the Younger and do not possess that characteristic cover of sand found on the latter. Denudation and deflation appear to have had sufficient time at their disposal to reduce the Older Gravels to their present condition. Again broadly speaking, therefore, each of the levels of the Older Gravels which have been distinguished in a somewhat preliminary manner, the 200-, 150- and 80-foot levels, is likely to represent a complex comparable with the group of the Younger Gravels.

Thus, the space of time covered by human industries in South Africa affords a relative chronology of four major damp phases, of which only the last has been well-studied and found to be composed of several oscillations. There is also evidence for an arid phase preceding this last damp phase (i.e. the First Wet Phase of the South

African scheme), and another dry period, with oscillations, following it and lasting more or less into modern times.[1]

The first three damp phases (Older Gravels) cover the evolution of human industries from pre-Abbevillian pebble industries to the Clacto-Abbevillian Stellenbosch I. The last damp phase (Younger Gravels, or First Wet Phase of South African workers) witnessed an Acheulian stage of culture with an incoming Levallois technique. The drier period that followed, with the interruptions of the Second and Third Wet Phases (Youngest Gravels and Schoolplaats Phase) has Fauresmith at the beginning, and the Middle and Late Stone Ages following, with the Levalloisian technique surviving into late phases.

We have to leave South Africa at this point, in order to discuss the possibilities of astronomical dating in Africa south of the Mediterranean zone.

D. THE PROSPECTS OF AN ASTRONOMICAL CHRONOLOGY OF THE AFRICAN PLEISTOCENE AND PALAEOLITHIC

Fluctuations of radiation in the tropics. Considering from the chronological point of view the climatic fluctuations which have been suggested in tropical Africa, one must admit that the evidence does not yet provide a relative chronology sufficiently detailed for the correlation with other areas. The attempts that have been made to correlate East African pluvials with glaciations in Europe were definitely premature, though in some instances the suggested correlation may not be far off the mark. But, in order to obtain a more secure basis for correlation, it is necessary to discuss briefly the implications for the tropical zone of the astronomical theory. For an introduction into this difficult matter, Zeuner (1944*a*, Chapter VIII) may be consulted.

Alternation of phases of great and small seasonal differences of radiation. If one constructs the curve of summer radiation for a tropical latitude, say 5° N., from Milankovitch's tables, one notices that the number of major maxima and minima was much greater than in the higher latitudes and their distribution more regular, the oscillations following each other about every 21,000 years. This is the expression of the dominating influence of the longitude of the perihelion in the tropics. From the chronological standpoint this would suggest that *if* the tropical pluvials depended on local fluctuations of summer and winter radiation in the same manner as do the

[1] The intensity of the Second and Third Wet Phases, and perhaps also of the Younger Gravels Phase III, was apparently *much* less than that of the period of the Younger Gravels I and II. On the profile from Weddburg to Windsorton (Söhnge, Visser and van Riet Lowe, 1937, pl. III) the Younger Gravels III are seen never to have been cut through by the modern river, the rock bench of the latter being the same as that of the former. Also, the Younger Gravels III aggradation appears to be still subject to flooding.

glacial phases of the northern hemisphere we should have many more pluvial phases than have been recognized, in fact so many that dating of any particular deposit would be wellnigh impossible. Now, the tendency of workers in East Africa generally has been to distinguish a much smaller number of pluvials, two or three, though with subphases. If this conception can be substantiated, it is clear that only the subphases might correspond to fluctuations in the seasonal amount of radiation, but not the major pluvials as a whole, into which they are grouped. It would be futile to suggest any correlation between pluvial subphases and radiation cycles.[1] It may be pointed out, however, that the large number of upper Pleistocene fluctuations in the levels of East African lakes which Nilsson (1940) was able to recognize are perhaps the result of these short-period oscillations (Zeuner, 1944*a*, p. 211, p. 217).

Meteorological and caloric equators. There is another aspect of the fluctuations of solar radiation which promises to supply an explanation of the *major* pluvials and, thus, a possibility of dating in years and of correlating the Pleistocene and its human industries in Africa with the glacial phases of Europe.

It is well-known that the *meteorological equator*, which separates the weather-régime of the northern and southern hemispheres of the earth and is given by the narrow belt of rising air called the *equatorial calms*, lies in the average [2] over about 5° N. lat., and not over the *geographical equator*. This phenomenon is usually explained as the result of the more intense circulation of the atmosphere over the southern hemisphere, but Wundt (1934, 1937) and Spitaler (1934) agree that the fluctuations of the *caloric equator* are a contributory cause. The caloric equator is the degree of latitude at which the minimum annual fluctuation of radiation occurs. In the zone enclosed by the caloric and the geographical equators, the amount of radiation received during the summer is *smaller* than that received during the winter. In this respect, therefore, it agrees with the opposite hemisphere in the seasonal rhythm of which it partakes. Thus, the caloric equator is the line on which the inversion of the seasons, as based on radiation, takes place.

The position of the caloric equator at various times in the past has been calculated by Milankovitch (1938, p. 662); it is shown here in the form of a graph (fig. 78). At the present, it lies at 3° N., so that one might deduce that, of the five degrees of average displacement of the meteorological equator, two degrees are to be attributed to the more intense circulation over the southern hemisphere, and three degrees to the position of the caloric equator.

When the caloric equator lies farther north, the circulation

[1] It is not even known whether a period with seasonal extremes of radiation, or a period of decreased seasonal differences, would produce a ' pluvial ' phase.
[2] More on continents, less over the oceans.

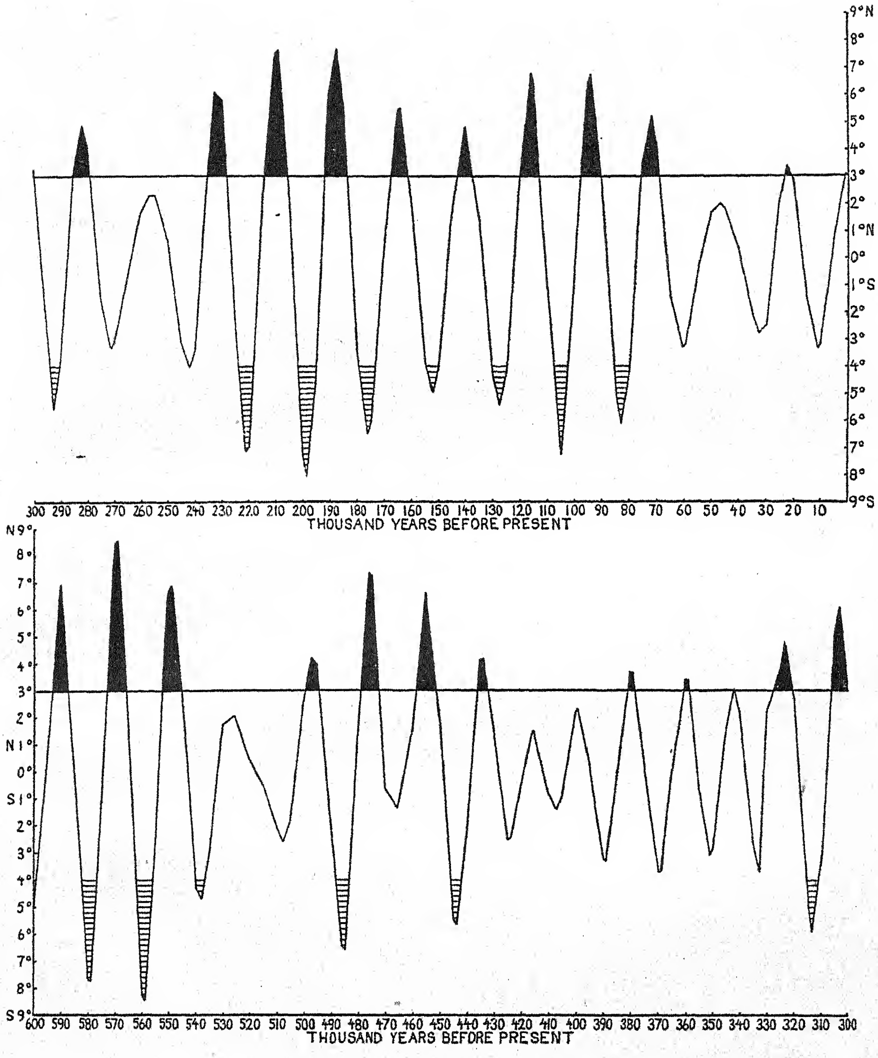


FIG. 78.—Positions of the caloric equator during the last 600,000 years. Deviations from the geographical equator of over 3 degrees to the north, black; of over 4 degrees to the south, hatched.—From Zeuner (1944).

effect is likely to become rather less than two degrees, and certainly not more. On the other hand, when the caloric equator moves south, the circulation effect is likely to increase to more than two degrees, and this amount has to be deducted from the position of the caloric equator in order to obtain the position of the meteorological equator.

Effect of the fluctuations of the caloric equator in the tropical zone. The effect on the tropical zone of this periodic oscillation is difficult to assess. So much is evident, however, that there were long periods of time when the caloric equator varied its position only moderately (see fig. 78), and others during which it swung north and south repeatedly with an amplitude of as much as 10 to 16 degrees (i.e. 5 to 8 degrees N and S of the geographical equator). During these phases of violent fluctuation, the geographical belt which is now the zone of equatorial rainfall may well have come to lie sufficiently far north or south to receive only a fraction of the rainfall it enjoys at present. But such phases must have been of short duration and alternated with phases of heavier rainfall every 21,000 years. A period of violent fluctuations of the caloric equator therefore would, in the tropical zone, result in deposits indicating a repeated alternation of dampness and dryness.

Apart from earlier periods of this kind, there is one between 235,000 and 70,000 B.P., which stands out for its long duration. Recalling the evidence from Uganda (p. 251), one is inclined to consider this period as a causal factor of the Kamasian with its several oscillations between wet and dry.[1]

No more can be said at the present about the tropical zone, and what has been said must be regarded as very tentative. The movements of the caloric equator would hardly have been worth the space devoted to them here, had not South Africa provided suggestive evidence for their significance.

Caloric equator and 'pluvials' of the Sahara. The effect of the extreme oscillations of the caloric equator on the northern and southern dry belts is more easily understood than that on the belt of tropical rainfall. Taking the northern, Saharan, belt first, it is easy to see that a northward displacement of the caloric equator would simultaneously bring about a northward shift of the northern limit of the monsoon rains. In other words, it would incorporate a strip of the southern Sahara in the Sahelian or even Sudanese belt, which receive sufficient amounts of rainfall in summer to support a regular and general cover of steppe or scrub.

On the other hand, a southward displacement of the caloric equator would result in a withdrawal of the monsoon, and part of

[1] This correlation would be reasonable also from the archaeological point of view, placing as it does the evolution of the middle-upper Acheulian and the Levalloisian into roughly the same period as in Europe.

the Sahelian (i.e. the edge of the Sudan) would become desert. There is abundant evidence for the southward extension of Saharan conditions during some time in the Pleistocene, in the form of fossil dunes in what is now the Sahelian belt with summer rains and steppe. There is the *Goz* country of north-east Kordofan and northern Darfur in the Anglo-Egyptian Sudan (Maxwell-Darling, 1934, 1936). From the Région du Tchad Murat (1937, p. 52) describes fossil dunes. Around Lake Tchad, evidence is found for two dune phases separated by a lake phase and apparently followed by the modern lake (Krenkel, 1938, p. 1,386, the last two publications with bibliographies), in the French Sudan, Chudeau (1925, 1931) described fossil dunes, and from Mauritania, Aufrère (1930). Huzayyin (1941, p. 76) has summarized part of this evidence.

The extension of Saharan conditions into the zone which at the present is reached by the monsoon, is a phenomenon which cannot be explained on the theory of generally increased rainfall which has so often been adduced to explain the tropical and Saharan pluvials. But the movements of the caloric equator provide a very simple and satisfactory explanation, and one could almost regard these fossil dunes as evidence that the movements of the caloric equator played an important part in the development of the Pleistocene climate of Africa.

The northward displacements of the caloric equator would have varied between two and five degrees. During the period, 235,000 to 70,000 B.P., it amounted to four degrees about four times. The possible effect on vegetation is most interesting. If we take the approximate boundary of the Sahelian belt of grass-land and dry scrub against the desert belt as a guide-line—it lies about 18–19° N. in West Africa and about 15–17° N. in the eastern part of the continent—the Sahelian type of vegetation would have covered the southern half or third of the present desert during these phases of northward displacement.[1]

Furthermore, such displacement would have brought into the reach of the regular summer rains the highlands of Adrar, Air, Tibesti and Ennedi, and perhaps even Ahaggar. Wadis which run northwards, towards the Mediterranean, would have carried the cover of vegetation still farther north.

Now, it is necessary to remember that the Mediterranean type of pluvial coincides with the minima of summer radiation of the

[1] Archaeologically it is important that the Sahelian, in spite of its dry-steppe character, is cultivated (Maxwell-Darling, 1934, p. 68). The same land is cultivated for several years, and then deserted for a period. 'The result is that most of the land has been cultivated at one time or another.' During a pluvial, therefore, even the Sahelian type of country, spreading over parts of the Sahara, would be quite sufficient to support even an agricultural population. Furthermore, the frequent change of the land might contribute enormously to the spreading of tools and other cultural remains over the surface and in the superficial soil, which is so characteristic of the later Saharan Stone Age.

temperate north, and with the retarded maxima of the glacial phases. These periods occurred simultaneously with extreme northward displacements of the caloric equator. *Thus, while the Mediterranean pluvial watered the northern fringe of the Sahara, its southern fringe enjoyed increased monsoon rainfall.* Though for meteorological reasons the dry belt is unlikely to have been obliterated completely, the phenomena described may well have led to its reduction to such an extent that, especially along the wadis and the chains of hills which extend across the Sahara (southern Algeria), steppe and scrub lands formed a continuous bridge from the Sudan to the Mediterranean.

The suggested explanation of the Saharan pluvials as the result of a northern position of the caloric equator coupled with a Mediterranean pluvial whenever there was a glaciation in northern Europe removes several difficulties encountered by other theories.

(1) Many workers, for instance Gautier (1935), have shown that the Sahara never was ‘ wet ’, and that the greatest increase of precipitation that ever happened produced Sahelian bridges across the desert belt. This is the picture we arrived at in our deduction.

(2) Some of the Saharan pluvials appear to have lasted for some considerable time. If the Saharan pluvials were nothing more than secondary effects of the glacial phases, not even the interstadials could have been bridged by damp conditions. But the co-operation of the caloric equator with the Mediterranean pluvials creates conditions which would favour the coalescence of pluvial phases into major pluvials. If we take, for instance, the first of the series of extreme displacements of the caloric equator which occurred between 235,000 and 70 B.P., this was contemporary with the glacial phase PGl_1. Considering the retardation of the expansion of the ice-sheet (p. 142) and the consequent extension of the corresponding Mediterranean pluvial, it is conceivable that the interval between this and the following extreme northward displacement of the caloric equator was considerably shortened, so much so that the store of underground water accumulated in the pluvial phase helped the vegetation to last through the short, dry, interval.

Theoretical sequence of African pluvials. If this idea is right, one would expect to find, in the Sahara, evidence of three pluvials in the lower and middle Pleistocene (590,000–550,000, 500,000–430,000, 330,000–280,000 B.P.), with a long dry interval between the second and the third, and with the third being relatively insignificent. The fourth pluvial was the longest of all, from 235,000 to 70,000 B.P. All these pluvials would be subdivisible into several oscillations. Although the subphases would not be contemporary in the Saharan, the tropical and the South African belts, the enumerated major pluvial periods would be roughly contemporary all over Africa.

The theory here proposed is, of course, subject to proof or dis-

proof afforded by palaeoclimatic evidence. As shown by Huzayyin's work (1941), however, the sequence of climatic phases in the Sahara is still unknown, except for a few casual glimpses which cannot be combined into a consistent picture. Future work will no doubt show whether the displacements of the caloric equator had the effect on the climate of the Sahara which has been tentatively ascribed to them in this chapter.

Caloric equator and 'pluvials' in South Africa. The same theory applies, *mutatis mutandis*, to South Africa. As has just been said, the major pluvial periods there would have been the same as in the Sahara, though the subphases would not have been contemporary. But the general picture, of three early pluvials separated by comparatively long intervals, and a fourth of a very long duration, would be the same. Now, if we turn back to our summary of the climatic phases found in South Africa (p. 261) we find that the evidence is not inconsistent with the theory of displacements of the caloric equator. The three earlier pluvials suggested by the curve, would be represented by the Older Gravels, the long fourth pluvial by the Younger Gravels, with the two latest oscillations representing the last subphases of the pluvial or, more likely, two of the three smaller oscillations which followed it (60, 35, 10,000 B.P.).

This correlation is not suggested as implying a high probability, but merely as a possible, and most tentative approach to using the astronomical theory in the dating of climatic phases and of human industries on the southern hemisphere. Only further palaeoclimatological work will be able to decide whether or not the theory of the displacements of the caloric equator is correct. The displacements as such are, of course, a fact; it is their climatic interpretation which is tentative. Since so many quantitative elements are involved in speculations of this kind that it is impossible to put forward a good case on a numerical basis, we shall have to wait and see whether new evidence confirms the postulates of the theory or not.

From the archaeological point of view, the dates for the South African Stone Age which might be deduced from the astronomical theory are reasonable. They are included, with a question mark, in the world correlation table, fig. 80.

E. ASIA, AUSTRALIA AND AMERICA

After the foregoing discussion of the evidence for the climatic chronology of the Pleistocene, and the absolute chronology derived from the astronomical theory, for Europe, the Mediterranean and Africa, it may be as well to pause and to summarize which methods of approach appear to be the most promising for the extension of the absolute chronology over the entire earth.

In trying to establish a relative chronology which can be dated

astronomically, the most reliable method is indubitably that of determining *with care* the exact mean sea-levels belonging to the various Pleistocene beach formations. It is naturally restricted in its application to coastal areas where suitable deposits occur, and from the archaeological point of view worth while only when the beaches contain implements. In areas where eustatic river terraces contain implements, these can be dated some distance up the river. In doing so, the mistake has been made of continuing beyond the limit of eustatic action, into that part of the river's course which is governed by a climatic cycle, and the opposite mistake of neglecting the eustatic phenomenon has been made also. This is not the place for the critical discussion of work on rivers in climates other than temperate, but it must be said that the conceptions of most authors are still far too primitive. In any case, the eustatic method will provide interglacial dates only.

The second method is the palaeontological one. Provided tolerably rich mammalian faunas are contained in the deposits, an estimate can be made as to its lower, middle, or upper Pleistocene age. The estimate is inevitably vague, and its uncertainty increases with the distance from Europe, especially in tropical climates. It yields even less detailed subdivisions than the first method, and yet it is important in countries where it is the only approach possible.

The third method is the investigation of the climatic rhythm of river aggradation and erosion, with the intention of establishing pluvial and interpluvial periods and phases. The difficulty here is that the local climate has to be duly considered and that no generalized scheme, or 'cycle', can be used as a clue. It will also be necessary to define the term 'pluvial' for the area studied, whether it implies increased annual total of precipitation, or increased seasonal floods, which are two very different climatic phenomena. I am confident that this approach will eventually provide the detailed chronology of the tropical countries and that this, in turn can be matched with the movements of the caloric equator, or the local radiation curves, or both, as the case may be. The best chances for applying this method are afforded by countries lying on the dry edges of the zones of tropical rainfall.

Finally, in countries outside the tropical zone, to which the detailed chronology of Europe cannot yet be applied, it will be possible, after an application of the eustatic and palaeontological methods, to work out a climatic chronology in the same manner as was done in Europe, using buried soils, eolian deposits, and the climatic cycles of the rivers.

In the following paragraphs, some attempts which have been made in Asia, Australia and America are briefly reviewed. They have been selected chiefly for their potential chronological import-

ance, either because they supply certain details of the relative chronology, or because they are concerned with fossil remains and important cultures of early man.

China. Pekin Man, Choukoutien. Although the place of Pekin Man (*Homo erectus pekinensis* = Sinanthropus) in the chronology of the Pleistocene is as yet somewhat uncertain, he is of such outstanding phylogenetic importance that a short discussion is justified. The skeletal remains from Choukoutien, near Pekin (40° N. lat.), have been described by Black (1934) and Weidenreich (1936, 1937, 1941, 1943). A summary of the geological, anthropological and archaeological evidence up to 1933 was presented by the original team of workers, Davidson Black, Teilhard de Chardin, C. C. Young, and W. C. Pei (1933). The anthropological significance of the skeletal remains was discussed by Weidenreich (1939), and the bone and antler industry described by Breuil (1932*b*, 1939). The accompanying fauna has been treated by Pei and by Young in volumes of the Palaeontologia Sinica (references and additions in Pei, 1939*a*). There are numerous other papers on this locality, among which Pei's attempt of a correlation with Europe (1939*b*) is of special importance in the present context. De Terra (1941) has undertaken a correlation with India to which we shall have to return.

Chronological position of Sinanthropus. The stratigraphy of the deposits in and near the caves of Choukoutien does not afford a means of dating. The only passable way, therefore, is that of palaeontology. It has been used by Pei (1939*b*) in the wisest manner possible, namely by distinguishing faunal assemblages representing successive phylogenetic levels, much on the same lines as employed in the distinction of the lower, middle and upper Pleistocene of Europe (Zeuner, 1944*a*, Chapter X). Working on these lines, Pei has shown that the Choukoutien fauna corresponds with the evolutionary level of the lower Pleistocene (chiefly ApIgl) of Europe. This, however, applies to the Sinanthropus locality only; other localities at Choukoutien have proved to be of later age.

The lower Pleistocene age of Sinanthropus as suggested by Pei, raises the question of the Plio-Pleistocene boundary. Pei, of course, arrives at a lower Pleistocene age since he adopts the prevalent European system. Teilhard de Chardin (1937) draws a slightly different line, assigning the whole of the Sanmenian (which is the stage preceding the Choukoutien stage) to the Pliocene, instead of its lower part only (Pei), but this appears to be due to nomenclatorial rather than factual differences, the Sanmenian I of Pei being the Sanmen or Nihowan stage of Teilhard. Both authors consider the Choukoutien Sinanthropus deposits plainly as of lower Pleistocene age. De Terra (1941), however, regards the Nihowan or Sanmenian (Chinese equivalent of the Villafranchian of Europe) as the lower Pleistocene, with the result that Sinanthropus becomes middle

Pleistocene. This is rather more than merely a matter of chronological nomenclature, since 'middle Pleistocene' conveys to the palaeontologist the impression of a much later phase in the evolution of the mammalian faunas than that represented by the Sinanthropus locality. It seems better to retain the boundary elaborated by Pilgrim (1944) which takes careful account of both eastern Asia and Europe.

The lithic industry of Sinanthropus, with quartz as main raw material, is atypical, with the exception of a few specimens. It is classed as lower Palaeolithic (Pei, 1939*b*). Breuil (1939) has shown that bones and antlers were utilized to a great extent, presumably because of the scarcity of suitable stone.

The absolute age of Sinanthropus and his industry is thus likely to be in the neighbourhood of 500,000 years; he stands comparatively close to Heidelberg Man in the chronological scale. But whilst the latter definitely dates from the end of the lower Pleistocene, a wide range within this subdivision is available for Sinanthropus.

Upper Cave, Choukoutien, Homo sapiens and Upper Palaeolithic. Attention should also be paid to a later deposit of the Choukoutien Hill, that of the 'Upper Cave", with its industry (Pei, 1939*c*, *d*), large numbers of bones of *Homo sapiens* (Weidenreich, 1939), and a rich mammalian fauna (to be described by Pei). The age of this deposit is claimed to be 'late Pleistocene' by Pei (1939*d*, p. 39) on faunal evidence. This point requires verification since the recent discovery of *H. sapiens* in Last Interglacial deposits in Australia (p. 278) suggests that modern man might date back to the middle Pleistocene in Asia. The industry is regarded as upper Palaeolithic; its lithic component is poor, but bone implements and ornamental objects are abundant. Weidenreich found that the three skulls typified three different racial elements, best to be classified as primitive Mongoloid, Melanesoid and Eskimoid.

North-west India, glaciations and Palaeolithic. The Pleistocene succession of north-west India is famous for its palaeontological contents. The lower series in particular, combined with fossiliferous Pliocene, is well-known under the name of the *Siwaliks*, after the Siwalik Hills at the foot of the Himalayas near Dehra-Dun, at 30° N. lat. and 78° E. long. The enormous mammalian material described by Falconer (1868) was drawn mainly from this area. In recent times, G. E. Pilgrim (1932) has greatly contributed to the advance of Plio-Pleistocene mammalogy in India. The climatic succession of north-west India has been investigated by de Terra and Paterson (1939) who succeeded in linking river terraces with moraines of Himalayan glaciations. Most of their evidence comes from Kashmir, and Potwar in the northern Punjab (near the Salt Range), at a latitude of 33 to 34° N. De Terra and Paterson also

discovered Palaeolithic implements which could be classified into industries.

North-west India, a mountainous country at a latitude where the fluctuations of radiation resemble those of Europe offers the unique opportunity of establishing a link between the temperate north and the tropical region. From de Terra and Paterson's studies it is evident that the connexion of moraines with aggradation terraces is much the same in north-west India as in the Alps. A section through the Indus terraces near the confluence with the Soan River is reproduced here (fig. 79). Apart from the Boulder Conglomerate forming the hill and containing glacifluvial deposits and moraine, five terraces can be recognized of which the second and fourth are glacifluvial. The others are regarded as interglacial stages. On this interpretation, and on the assumption that the glaciations of the Himalayas were contemporary with those of

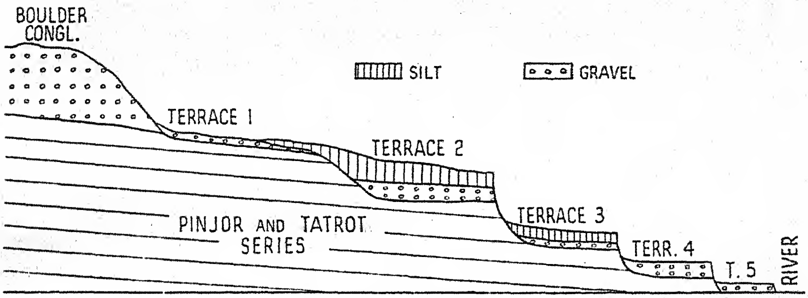


FIG. 79.—The sequence of terraces of the Indus River, near the confluence with the Soan.—After de Terra and Paterson (1939, fig. 181), modified.

Europe, the fourth terrace would correspond to the Last Glaciation, the second to the Penultimate Glaciation, and the Boulder Conglomerate to the Antepenultimate Glaciation. Note (8), p. 389.)

On the other hand, if one accepts the astronomical theory, considers the glacial phases of the western Himalayas as the products of the local fluctuations of solar radiation and the influence of the Mediterranean pluvials,[1] one would expect to find a sequence of *glacial phases* similar to those of the Alps, subdividing the major glaciations. The sequence of five terraces following the Boulder Conglomerate indeed suggests such a succession, provided one interprets the 'interglacial' terraces of de Terra and Paterson as representatives of less intense glacial phases. In this case, the first and second terraces would correspond to PGl_1 and PGl_2, and the third to fifth to three stages of the Last Glaciation.[2] This very tentative

[1] Barometric depressions from the Mediterranean are known to reach north-west India occasionally even at the present time.

[2] Whether these are LGl_1, LGl_2 and LGl_3 of Europe is not quite certain since, in the lower latitudes, a summer minimum at 94,000 B.P. becomes prominent.

interpretation of the Indus terraces is supported by the great erosional gaps between the glaciations, and the much smaller gaps between the suggested glacial phases, namely,

Erosional gap		
Boulder Conglomerate—Terrace I	300 ft.	= Penultimate Interglacial ?
Terrace I—Terrace II	70 ft.	
Terrace II—Terrace III	230 ft.	= Last Interglacial ?
Terrace III—Terrace IV	60 ft.	
Terrace IV—Terrace V	50–60 ft.	
Terrace V—Present River	30–40 ft.	

I am fully aware of the insecure foundation of this comparison, since the thicknesses of the aggradations resting on the benches had to be neglected, but the resulting sequence is highly consistent, and the Boulder Conglomerate is, as in de Terra and Paterson's interpretation, assigned to the Antepenultimate Glaciation.

As regards the pre-Boulder Conglomerate succession, Pilgrim (1944) has corrected the conception that the Tatrot zone of the Upper Siwaliks corresponds to the Early Glaciation. Instead, he suggests that the Bain Boulder Bed from the north-west Frontier Province (Morris, 1938) which can be dated palaeontologically as Pinjor stage or slightly later (see table, p. 275) is the equivalent of the Early Glaciation. Pilgrim further draws the Plio-Pleistocene boundary above the Villafranchian, immediately below the Early Glaciation (as done in the present book), while De Terra includes the Villafranchian, and with it the Pinjor and Tatrot zones, in the Pleistocene. The reasons why Pilgrim's practice is to be preferred have been given elsewhere (Zeuner, 1944*a*, p. 174). The ensuing relative chronology of north-west India, which is still tentative, with the human industries as determined by Paterson, is as follows (summary of industries in de Terra and Paterson, 1939, pp. 294–295): (table, p. 275).

It is remarkable that, in this tentative chronology, the relation of the early Acheulian and the appearance of the Levalloisian technique to the Penultimate Glaciation are about the same as in Europe; the Clactonian technique is observed in the rolled state in the early Soan B and C assemblages of Terraces I and II, but Paterson (in de Terra, p. 307) mentions the coming in of Levallois-like cores in the same assemblages, which he dates from the Penultimate Interglacial since he and de Terra regard Terrace I as an interglacial one. Also, the late Levalloisian would have persisted into the early part of the Last Glaciation and the late Palaeolithic appeared in the middle phase of this Glaciation, roughly at the same time as in Europe.

Burma. Irrawaddi terraces and Palaeolithic. Burma promises to become a further link between the temperate zone with its detailed Pleistocene chronology and the tropical zone with its suggested pluvial phases. Following the discovery of Palaeolithic tools by

Last Glaciation	Terrace V Terrace IV Terrace III	? Late Palaeolithic Late Levallois (cf. Late Soan), less rolled than derived earlier artefacts
Last Interglacial	Erosion	
Penultimate Glaciation	Lower beds of "loess" Terrace II Terrace I	Late Soan (Levallois flakes dominating over pebbles) Early Soan (cf. Clactonian, but also Levalloisian technique appearing, with cores and flakes with prepared platforms Rolled early Acheulian, flakes, and Early Soan (pebble industry)
Penultimate Interglacial	Erosion	
Antepenultimate Glaciation	Narbada Beds + Upper Boulder Conglomerate	Upper Boulder Congl. with large crude flakes
Antepenultimate Interglacial	Lower Boulder Conglomerate	
Early Glaciation	Bain Boulder Bed	
Villafranchian	Pinjor stage	
? Astian	Tatrot stage	
Pontian	Dhok Pathan stage	
Upper Miocene	Nagri Chinji stage	

Morris (1932, 1936), the Irrawaddi River has been studied by de Terra and Movius, and the mammalian faunas determined by Colbert (1943). The five terraces are regarded as aggradations during pluvial phases which can be correlated with glaciations. The climatic aspects of the Irrawaddi terraces (north of 20° N. lat.), in the zone of summer rains and dry season, certainly deserve a close palaeoclimatological study.

The implements found are classified by Movius under the name of Anyathian; many were made from fossil wood. Most of them are chopping tools, and flakes are few. There is some resemblance with the early Soan of north-west India, but the Anyathian is a local culture which runs through from Terrace I (considered of Narbada age, i.e. early middle Pleistocene or final lower Pleistocene in our system) to the Neolithic.

Java. Pithecanthropus, Homo soloensis, &c. Java occupies a prominent place in the history of early man on account of the large

number of fossil hominids found there. Since Dubois discovered the first Pithecanthropus (1892), further human remains have come from several localities, so that at the present, three main types are represented, *Homo erectus* (Pithecanthropus), *H. soloensis*, and *H. sapiens*. The chronology of the Javanese Pleistocene, therefore, is a matter of great importance, but little systematic work has as yet been done (see for instance Duyfjes, 1936).

A very full report on Java has recently been written by de Terra (1943), to which the reader may resort for more detailed information than can be given here. Most of the recent discoveries were made by von Koenigswald (1936*b*, 1937*a*, *b*, 1938) ,while *H. soloensis* was found by Oppenoorth (1937 ; Haar, 1934). Von Koenigswald has paid attention to the Pleistocene succession and has worked out the mammalia of many localities (1934, 1937*a*, 1939), as well as the finds of Palaeolithic implements (1936*a*).

The geographical position of Java has tempted workers to correlate its Pleistocene deposits with those of India and Burma. In doing so, it must not be forgotten that the distance, both in miles and in terms of climatic zonation, is very great. Java lies at 7° S. lat., not less than 27 degrees of latitude south of Burma, and 41 degrees south of that part of north-west India which has been studied in some detail. Climatically, it occupies at the present a position just on and outside the southern border of the equatorial belt of rain at all seasons, where a dry season begins to make itself felt (comp. Zeuner, 1941). Java thus lies in the difficult zone in which the climate is likely to have fluctuated between rain at all seasons and a seasonally dry climate, in accordance with the oscillations of the caloric equator during the Pleistocene. How such changes would have acted on the rivers, is very difficult to make out without a detailed investigation. The problem is further complicated by the frequent over-supply of load to the rivers by the volcanoes, and by the neighbourhood of the sea. De Terra (1943) regards the influence of eustasy on the Javanese rivers as negligible, and he may well be right in connexion with certain sites, but generally speaking it is inconceivable that the rivers of a narrow island like Java should show no evidence of eustatic fluctuations. Knickpoints started by low sea-levels must have played a great part in the history of the upper courses of the rivers. Considering all these difficulties, none of which has as yet adequately been dealt with, and considering the separation of Java from the Indian mountain ranges by the equatorial zone, a correlation of river aggradations in Java with glaciations in north-west India, as undertaken by de Terra, is a venture which can only be called premature.

In order to obtain some rough dates for the important finds made in Java, therefore, the palaeontological method has had to be resorted to. Here, again, considerable difficulties are met with.

It is not easy to derive reliable conclusions from the comparison of faunas separated by some 30 to 40 degrees of latitude and by the equatorial belt. This difficulty has been fully realized by most palaeontologists in Java, but, faute de mieux, the Siwaliks still remain the standard of reference for Plio-Pleistocene faunas in south-east Asia.

A second difficulty is involved in the practice of some authors of calling the Villafranchian the lower Pleistocene, and the lower Pleistocene of our system, the middle. This has to be kept in mind when reading papers on Java.

The javanese succession given in the following table is composite. Some of the sites are in eastern Java (Kendeng Hills), others in central Java (Solo River). At the present moment the succession may be computed in this manner (partly after de Terra, 1943*b*, p. 455, otherwise based on von Koenigswald's papers):

Stratigraphy	Correlated Indian fauna	Suggested division
Silt terraces (T_3) and high flood-plains SAMPOENG FAUNA—Proto-Australoid people Volcanism and uplift with tilting	(Recent)	Postglacial
Erosion : formation of terrace T_2 Volcanism and earth-movements WADJAK MAN (?) (fissure deposit)		Upper Pleistocene
Stream aggradation, T_1 NGANDONG FAUNA—*Homo soloensis* [1] Volcanism	(Fauna of almost Recent type)	
Erosion and uplift NGANDONG FAUNA Volcanic Lahar deposits		
——Disconformity——		
Erosion and strong uplift Aggradation of the synclines		
Kaboeh Beds, fluviatile TRINIL FAUNA—Selenka's Trinil Fauna. Pithecanthropus. Flakes cf. Clactonian, some a primitive ' Levallois '	Narbada and Boulder Conglomerate	Final lower or early middle Pleistocene
Poetjang Beds, estuarine and fluviatile, with volcanic material DJETIS FAUNA—Dubois' Trinil Fauna. *Homo modjokertensis*	Somewhat later than Pinjor	Lower Pleistocene or late Villafranchian
KALI GLAGAH FAUNA	Pinjor	Villafranchian
TJI DJOLANG FAUNA	Tatrot	Astian

[1] With bone industry, including a ' barbed spearhead ' (von Koenigswald, 1937).

Considering the great difficulty of separating, even in Europe, the Villafranchian from the lower Pleistocene, the Djetis Fauna, with the infant skull of *H. modjokertensis*, may be regarded either as late Villafranchian or lower Pleistocene, since it is more advanced than the Pinjor Fauna. The Trinil Fauna, with Pithecanthropus, is perhaps late lower Pleistocene, or early middle, depending on what position will finally be given to the Narbada Beds. The Ngandong Fauna, with *H. soloensis*,[1] is regarded as upper Pleistocene because it differs but little from the Recent fauna. In view of the primitive features of *H. soloensis* this is remarkable and deserves closer attention.

Australia, ancient beaches. Since the climatic phases of the Pleistocene of Australia have not yet been worked out in detail and since the glacial phases distinguished in Tasmania and eastern Australia cannot yet be correlated with those of Europe (in spite of several attempts which have been made), the succession of coastal terraces is the only available means of correlation with other continents. Among the authors who produced evidence for eustatic correlation are Tindale (1933), Lewis (1934) and Edwards (1941), from whose studies in South Australia the following tentative sequence may be deduced:

Mediterranean equivalent	Tindale, S. Australia	Lewis, Tasmania	Edwards, N.W. Tasmania
	(75 m.)		
Milazzian	60 m.		
	(45 m.)		
Tyrrhenian	27 m.	30 m.	(30 m.)
Main Monastirian	19·5 m.	15 m.	15 m.
Late Monastirian	7·5 m.	4·5 m.	4·5 m.

This sequence, to which I have added the altimetrically equivalent beaches of the Mediterranean area, may be of use in fixing a date for the only accurately datable find of fossil man in Australia, the Keilor Skull. If the correlation suggested later (which is the same as that of the original authors) can be substantiated, extremely important conclusions are to be drawn.

Evidence for Pleistocene man in Australia. A valuable summary of the fossil remains of man found in Australia has recently been published by Mahony. Only the Talgai Skull and the Tartanga skeletons need be mentioned (except, of course, the new find from Keilor). Although the Talgai Skull (from Queensland) was heavily mineralized, its geological position is uncertain. The Tartanga skeletons (from South Australia, Hale and Tindale, 1928) proved to

[1] According to Weidenreich's latest view (1943) *H. soloensis* is more primitive than *H. neanderthalensis.*

be of 'some antiquity', and Tindale is inclined to think that they date from the phase of aggradation leading up to the lowest beach terrace which, presumably, is the equivalent of the Late Monastirian.

Keilor skull. This age (latter half of Last Interglacial) might appear too early for man in Australia, but it is eclipsed by the discovery at Keilor, near Melbourne, of two mineralized skulls and parts of skeletons, at the depth of 18 feet below the surface, and 45 feet above the river, in a sandy, fluviatile terrace (Mahony, 1943*a*, *b*).

The first skull has been described by Wunderly (1943), and the teeth and the palate studied by Adam (1943). Wunderly comes to the conclusion that the skull combines Australoid and Tasmanoid characteristics in about equal proportions. But Wood Jones (1944) points out that this is by no means convincing and that a number of difficult implications would arise if it were true. There is no question, however, that the skull belongs to *Homo sapiens*.

The evidence for the Pleistocene age of the skull (Mahony, 1943*b*) is its position in an undisturbed deposit, 18 feet below the surface of the Keilor Terrace of the Maribyrnong River. The surface of this terrace is 103 feet above low-water mark at the locality, and 60 feet above L.W.M. at its southern end nearer the sea. The course of the present river near the southern end of the terrace is reached by the tides. The tidal amplitude being only two feet, the mean sea-level at the time when the aggradation of the Keilor Terrace came to an end may be presumed to have been somewhere in the neighbourhood of 60 ft. This is almost exactly the level of the Main Monastirian Phase in other parts of the world (18 metres), so that Mahony's suggestion that the skull dates from the Last Interglacial, receives strong confirmation. More precisely, it appears to date from the earlier part of this interglacial, from the time when the Main Monastirian beach had not yet been built up to its maximum height. We may tentatively assign to it an age of about 150,000 years.

It is most desirable, however, that supplementary evidence for the geological age be brought forward, either by means of a detailed study of the coastal terraces and the river terraces connected with them, or perhaps on palaeontological grounds.

Homo sapiens in Australia contemporary with H. neanderthalenis in Europe. The inference to be drawn from this discovery is that *Homo sapiens* was present in Australia when *H. neanderthalensis* lived in Europe (Zeuner, 1944*b*). Since there is no reason to suppose that *H. sapiens* originated in Australia, he must have immigrated into this continent, most probably from Asia, either early in the Last Interglacial, or during the Penultimate Glaciation, when the sea-level was exceptionally low. This conclusion corroborates the view which is beginning to be held generally, and especially on the strength of the Swanscombe Skull, that *H. sapiens* evolved during

the Penultimate Interglacial, if not even earlier, and probably somewhere in Asia.

A second inference to be drawn from the Keilor Skull is that (though no artefacts were found with the fossil) the upper Palaeolithic culture which has always been associated with *H. sapiens*, might be rather earlier in Asia than in Europe. It need not, of course, be so, since *H. sapiens* is also known to have manufactured an Acheulian industry (at Swanscombe), but the possibility of the evolution of the upper Palaeolithic during the Last Interglacial has to be reckoned with.

Appearance of man in North America. Fossil man and human artefacts found in America have, up to the present, suggested a very late immigration of *H. sapiens* into that continent. The evidence for geological antiquity has been subjected to rigorous criticism, and those finds which may be regarded as reliable, date American man back to some late phase of the Last Glaciation. Excellent summaries on early man in America, by Hrdlička, Spinden, MacClintock, Antevs, Gladwin, Bryan, Roberts and Sellards are found in the Symposium on Early Man (Philadelphia, 1937). The most interesting finds, in this case artefacts, are the Folsom industry. Some evidence of its age has been given in Chapter II (p. 33 ff.). It may suffice, therefore, to refer again to Howard's monograph of the industry (1935), and the recent publication by Bryan and Ray (1940) on the Lindenmeier Site in Colorado. These authors studied terraces and moraines in the neighbourhood of the site and found that the Folsom culture is at least as old as the Cochrane Stage of the Wisconsin (= ?Fennoscandian stage in Europe), but later than the St. Johnsbury stage (correlated by Bryan and Ray with the Pomeranian). Relying on varve countings, they assign to the Folsom culture an age of from 10,000 to 25,000 years, considering the real figure to be rather nearer the higher value.

W. A. Johnston (in Jennes, 1933), and Antevs (1935) hold that approximately at that time, 20,000 to 15,000 years ago, a passage opened for man to migrate from Asia to the Great Plains. They argue that, during the maximum of the Wisconsin, the ice-sheets of the Keewatin and Cordilleran centres were connected and that at an early stage of the retreat the two became separated, so that man arriving from Siberia via the Bering Straits (the sea-level was low at that time) was able to penetrate to the open country of central and south-western America.

Conclusion. There is no need to add a summary to the sketchy survey of Asia, Australia and America. The Pleistocene chronology of most countries involved is in such an embryonic state that dating is hardly more than an act of reasonable guessing, mostly on a palaeontological basis. In view of the importance of some of the finds made, especially in Choukoutien, Java, and south-east Australia,

even such tentative dates are not useless. In North America, Pleistocene chrononology is, of course, highly developed, though not yet linked in any detail with the absolute chronology. This work remains to be done; but early man is so late in North America that the detailed chronology of the finds would add but little to the world-wide problem of the evolution of man.

CHAPTER IX

THE CHRONOLOGY OF EARLY MAN AND HIS CULTURES

Reviewing as a whole the archaeological chronology developed in the last three chapters, one might say that it has revealed little that is new. Nearly every one of the datings given has been suggested before and, as regards the correlation tables, many others have been published that contain much fuller information. Yet, to attempt a reasonably consistent picture of the knowledge available at a given time, with a view to being comprehensive, is one thing, and to concentrate on a presentation of the established evidence, checked by various methods, and to eliminate subjective interpretations, is another. Both tasks have to be carried out from time to time in every science. This book has, as should be obvious, the second object in view, and this renders it unavoidable that the general picture resulting from the evidence treated in it contains a number of blank patches.

Nevertheless it is advisable, after our hurried tour around the world, to summarize the evidence collected, in order to see how consistent a chronology it affords and what problems arise from it. This is done here with the aid of two tables, one showing the industrial stages (fig. 80), and another the skeletal remains of early man (fig. 81).

In both tables two degrees of reliability are distinguished, (*a*) the high one of 'age geologically established', i.e., of an industry or specimen having been found in a deposit which, in the author's opinion, has been dated unambiguously on non-archaeological grounds, and (*b*) the tentative one, which is less certain either because close, detailed dating is still impossible, or because the determination of the industry or specimen is open to criticism. *It is indicated by italics.* It will be seen that in the archaeological table the higher category is confined to Europe and the Mediterranean, while in the anthropological table many European specimens are tentatively placed, because geological evidence for their age is below the standard adopted in our chronology, so that they had to be dated by their associated industries. In view of the close succession of industrial phases of the upper Palaeolithic (to

which most of the remains in question belong), however, the margin of error involved is likely to be small.

The logical order might seem to be to discuss Man first and then his tools, but, since the chronology of industries is supported by so much more evidence than that of their makers, it is preferable to discuss the industries first.

A. ARCHAEOLOGICAL CHRONOLOGY

(Fig. 80.)

Core, flake and blade cultures. The distinction of core (or hand-axe), flake and blade cultures adopted in the table is clearly an over-simplification, but it accords with the classification in vogue at present. The interrelations between the three groups constitute a typological problem which cannot be discussed, but from the chronological point of view it is interesting that in Europe the hand-axe cultures are finally absorbed by the Levalloisian and Mousterian at the end of the Last Interglacial. The flake cultures, in turn, last into the second phase of the Last Glaciation in some localities, and in the Pontine Marshes perhaps even longer, but in most areas of Europe they disappear with the first phase of the Last Glaciation. The appearance of blade cultures in the form of the Aurignacian is often considered as a clear-cut substitution which took place during the interstadial $LGl_{1/2}$. This is so where middle or upper Aurignacian immediately follows Levalloisian or Mousterian, but in areas where the Mousterian is followed by lower Aurignacian (Chatelperronian) the transition from the 'middle' Palaeolithic 'flake' culture group to the upper Palaeolithic 'blade' group is less sharp. In Palestine, implements of the lower Aurignacian type appear in the Micoquian as early as during the Last Interglacial and are present in appreciable numbers in the lower Levalloiso-Mousterian at the end of this interglacial, though rare in the upper Levalloiso-Mousterian (pluvial corresponding to LGl_1).

In South Africa, it is difficult, if not impossible, to distinguish core and flake cultures, as has been repeatedly emphasized by van Riet Lowe (1937, &c.), Goodwin (1935) and Cooke (1941), and the blade cultures appear only in the microlithic form, and combined with the Levalloisian flake technique.

West and central Europe. Gap of Antepenultimate Glaciation. The west and central European part of the table shows a curious gap, the Antepenultimate Glaciation itself having yielded no identifiable industry.[1] This gap was perhaps caused by the intensity of the second phase of the Antepenultimate Glaciation. It is quite conceivable that during this first very intense glaciation man was

[1] One scraper-like quartzite flake has been described by Soergel (1926) from the second Preglacial Terrace ($ApGl_1$) of Thuringia.

still ill-adapted to the climatic conditions of periglacial Europe and therefore on the whole avoided this zone.

Hand-axe industries. The European succession begins with the pre-Crag implements of East Anglia, some of which are probably of pre-Pleistocene Age. Other pre-Pleistocene implements have been described as 'Abbevillian' from Moroccan and Portuguese beaches of suggested Sicilian age. The exact relation of these implements to the beach deposits needs close investigation, since if their contemporaneity with the formation of the beach and their unquestionable 'Abbevillian' character can be proved, the latter industry would have begun in the Villafranchian.

At the beginning of the Pleistocene we encounter the core and flake industries of the East Anglian Crags (Ipsvician, Norvician, Cromerian) which, as agreed by several authorities, developed up to an Abbevillian stage. If this is so, the Abbevillian would have evolved from industries of the Crag type in the course of Early Glaciation times. This appears to me easier to understand than the suggested existence of Abbevillian in pre-Pleistocene times. This only shows how important is the careful geological dating of implements, and we must hope that the research which is being continued in Morocco and Portugal will produce the required evidence.

In the Antepenultimate Interglacial the Abbevillian is the characteristic culture. Whether the flake industry named Clactonian I is entirely independent of the Abbevillian, is not known, but it is clear that the root of the typical Clactonian of the Penultimate Interglacial is to be found in the flake industry of the Antepenultimate Interglacial. The allocation of the Abbevillian to this interglacial, proposed by Commont long ago and upheld by Breuil, is confirmed by geological evidence from western Europe. The German view which assigned it to the Penultimate Interglacial must be abandoned.

In the Penultimate Interglacial we meet with the lower Acheulian. Though many lower Acheulian tools are very typical, there are plenty of reminiscences of the Abbevillian in this stage, so that its evolution from the Abbevillian cannot be doubted in spite of the gap caused by the Antepenultimate Glaciation. In view of the great difficulty of distinguishing middle from upper Acheulian (Bowler-Kelley, 1937, p. 7), and of separating the lower from the middle (Bowler-Kelley, 1937, p. 6, 'Cagny'), no definite stage of the developed Acheulian can be assigned to the Penultimate Interglacial. It is clear, however, that by the end of this interglacial the Acheulian had acquired all its characteristic attributes, like ovates and the S-twist. The Acheulian of the end of the Penultimate Interglacial is called middle by some, and late by others, but it is futile to argue over this; strictly speaking, only three stages of the Acheulian are typologically distinguishable, lower (Breuil's I–II, Commont's Chellian), middle (Breuil's III–V), and Micoquian.

TIME SCALE	RELATIVE CHRONOLOGY	WEST AND CENTRAL EUROPE C	WEST AND CENTRAL EUROPE F	WEST AND CENTRAL EUROPE B	NORTH. MEDITERRANEAN C	NORTH. MEDITERRANEAN F	NORTH. MEDITERRANEAN B
				MESOLITHIC			MESOLITHIC
25000	LGl$_3$			PRE-TARDENOIS; FINAL MAGDAL. (CRESWELLIAN)			?cf. *Magdalen.* (CAPSIAN INFLUENCE)
				MAGDALENIAN (CRESWELLIAN)		?*Mousterian*	MAG.; MICROLITHIC; GRIMALDIAN (CAPSIAN INFLUENCE)
72000	LGl$_2$		PIN HOLE MOUST.; FINAL LEVALL.	SOLUTRIAN; UPP. AURIGNACIAN (CRESWELLIAN)		MOUSTERIAN	SOLUTR.; GRAVETTIAN (GRIMALDIAN; CAPSIAN INFLUENCE)
			PIN HOLE MOUST.; FINAL LEVALL.	MID. AURIGNACIAN; AURIGNACIAN		MOUSTERIAN	MID. AURIGNAC.
115000	LGl$_1$		MOUST.; LEVALL. V			MOUSTERIAN	
	LIgl	MICOQUIAN; *Upper Acheulian*	MOUSTERIAN; *Tayac.*; *Levall. V*; MIDDLE LEVALL.		ACHEULIAN	MOUSTERIAN; "MOUSTERIOID"	
187000	PGl$_2$	MIDDLE ACHEULIAN	MIDDLE LEVALLOIS				
		MIDDLE ACHEULIAN				"MOUSTERIOID"	
230000	PGl$_1$		EARLY LEVALLOIS				
	PIgl	MIDDLE ACHEULIAN; LOWER ACHEULIAN	?*Levallois technique appearing?*; CLACTONIAN II		*(Abbevillian present but not dated)*	CLACTONIAN	
435000	ApGl$_2$				*(Abbevillian present but not dated)*		
					(Abbevillian present but not dated)		
476000	ApGl$_1$				*(Abbevillian present but not dated)*		
	ApIgl	ABBEVILLIAN	*Clactonian I*		*(Abbevillian present but not dated)*		
550000	EGl$_2$	CROMERIAN	CROMERIAN				
		NORVICIAN	NORVICIAN				
590000	EGl$_1$	IPSVICIAN	IPSVICIAN				
VILLAFRANCHIAN		?*Abbevillian on Sicilian in Morocco*	?*pre-Red Crag flakes*				

FIG. 80.—Chronology of the Palaeolithic in different regions of the world.

PALESTINE			North West India			South Africa			GEOL. SUB-DIVISIONS
C	F	B	C	F	B	C	F	B	
		Mesolithic					*Lev. techn. surviving*	*Later Stone Age*	POST-GLACIAL
						Middle Stone Age (advanced Levallois)		*Solutrian-like laurel-leaf*	UPPER PLEISTOCENE
		ATLITIAN MID. AURIG.			*? Upper Palaeolithic*	*Fauresmith (Micoquian + Levallois)*			
		MID. AURIG. CHATELPER.				*Stellenbosch continued with Micoquian types*			
	UPPER LEV.-MOUST.								
	LOWER LEVALLOISO-MOUSTERIAN			*Late Levallois*					
↑ *cf. Micoquian* ↓		LEVELS WITH UP. PALÆOLITH FACIES							
CF. MICOQUIAN UP. ACHEUL.				*Late Soan (Levallois technique) Early Soan (with some Levallois technique)*		*Stellenbosch (Acheulian + Proto-Levallois)*			MIDDLE PLEISTOCENE
	? Tayacian		*Early Acheulian and Early Soan (pebble industry)*			*Early Stellenbosch (Clacto-Abbevillian)*			
				Large crude flakes		*Pre-Stellenbosch pebble and flake industries*			LOWER PLEISTOCENE
									PLIOCENE

Tentative datings in *italics*. C : core; F : flake; B : blade industries.

In the Last Interglacial, the middle or upper Acheulian persists. There is some evidence for its presence during the Penultimate Glaciation in northern France, but generally speaking it is absent from the 'cold' deposits of Europe. Later in the Last Interglacial it develops into the Micoquian which appears to have persisted until the climate changed to the cold conditions of LGl_1.

The interesting feature of this evolution of the hand-axe industries is the small amount of change observed, notwithstanding the huge time-span covered. Judged by the standards of, say, the upper Palaeolithic, the evolutionary rates of the Crag industries and of the Abbevillian, covering about 60 thousand years each, are small; but smaller yet is that of the Acheulian which lasted through 300 thousand years of which something like 200 thousand years appear to have been occupied by the 'middle stage' (Ach. III to V). This conservatism of the Acheulian is one of the most striking phenomena in the chronology of the Palaeolithic.

Flake industries. Among the flake industries, the Clactonian is contemporary with the Abbevillian and the lower Acheulian, and in technique it is indeed not unrelated to the former. It would be interesting to know whether the Clactonian actually persisted through the Antepenultimate Glaciation in the periglacial zone. In the earlier part of the Penultimate Interglacial it is in the typical stage, Clactonian II. This is definitely prior to the appearance of any Levalloisian. Whether the so-called Clactonian III, or High Lodge industry, belongs to the late Penultimate Interglacial, or to the Last Interglacial, has not been decided. Geological evidence tends to support the earlier age, but the typological step from Clacton II to Clacton III is great indeed. This, however, may be explained by an absorption of Acheulian methods by the Clactonian tool-makers (Hawkes, 1940, p. 16).

The first appearance of the Levalloisian technique is to be considered as an event of first magnitude since it involves a greater amount of foresight in the making of tools. The (fractured or unfractured) raw material is not directly shaped into the tool, but a core specimen essentially different from the desired tool is made first, and then the tool from a flake struck from the core thus prepared. It is of greatest interest, therefore, to watch the first traces of Levalloisian technique coming in.

In western Europe the Levalloisian *as an industry* is present in the first cold phase of the Penultimate Glaciation. Whether the technique appeared earlier than this, is uncertain. At Swanscombe (100-foot terrace) where the implements have been studied most carefully, Hawkes inclines to the view that no real Levalloisian is present (Swanscombe Report, p. 44), whilst Warren (*l.c.*, p. 47) attaches more importance to the few flakes with prepared striking platforms that have been found, considering the Levalloisian

as a continuous development from the Clactonian, during the time of the Swanscombe aggradation (PIgl). In Germany, flake industries referable to this interglacial have sometimes a Levalloisian aspect. On the whole, therefore, the appearance of the Levalloisian technique in (probably the latter part of) the Penultimate Interglacial is to be presumed.

The Levalloisian is, generally, a conservative culture. The early Levalloisian (Breuil's I–II) and again the early upper Levalloisian (Breuil's V) include large, coarse flakes. It is curious that both occur at the beginning of a glaciation (PGl_1 and LGl_1, respectively), when the climate was turning cold. There may be an ecological reason for the adoption of large flakes under certain climatic conditions.

The Levalloisian lasted for some 180,000 years in Europe. It finally disappeared during LGl_2. In South Africa, however, it has survived practically into modern times.

The term Tayacian has lately been applied by some to Clactonian-like flake industries which precede the Mousterian or are later than Clactonian II, and it is often suggested that they might be the 'missing link' between the two, the Tayacian being the parent of a Mousterian which, originally, showed no Levalloisian admixture. But it has not yet been made clear what is understood by 'Tayacian' when so used, since Breuil, when proposing the name, defined it as an industry 'à éclats où la technique du plan de frappe préparé s'introduit et s'associe avec la taille clactonienne' (1932, p. 184). Surely, if this is the original definition, 'Tayacian' cannot be confined to industries with Clactonian flakes and without any Levalloisian influence. For the time being, therefore, Tayacian appears to be used by many typologists for any kind of rough, Clactonian-like industry which cannot be classified as Clactonian I, II or III, and which often is patently due to poor raw material. The appearance of 'Tayacian' in our table, therefore, should not induce the reader to speculate on its chronological relations to other industries. Quite probably, many 'Mousterioid' industries mentioned in literature are of the same type.

Mousterian in the modern sense excludes, of course, the Levalloisian. It is the product of cultural fusion, a flake industry having adopted Acheulian methods of *retouche*, and to some extent even tool forms. At the moment the opinion is widely held that the 'true Mousterian' is free from Levalloisian influence, and due to a fusion of Tayacian and Acheulian elements. As pointed out in the preceding paragraph, the Tayacian itself sometimes used the Levalloisian technique. It is difficult to understand, therefore, how a 'pure' Mousterian could exist. Indeed the industries from the type site of Le Moustier reveal that even in the lower layers of 'pure Mousterian' typical Levalloisian flakes occur; and that the

Levallois technique was thereafter in use throughout the deposit. In La Quina, however, Levallois flakes are apparently absent,[1] but this is not the type site of the Mousterian.

The combination of Levalloisian, Acheulian and Tayacian or Clactonian elements which resulted in the Mousterian industry of Europe occurred during the Last Interglacial. No Mousterian site is known which dates from the first part of this interglacial. It begins at a time when the climate was mild, when the Acheulian blossomed out into the Micoquian, and when the middle Levalloisian was nearing its end, whilst 'Tayacian' preceded it in the earlier part of this interglacial. Conditions for the fusion of the three elements, therefore, were favourable. This fusion was hardly a unique event, and the great variability of the Mousterian suggests that local and temporary influences from outside played a great part in modifying it.

The fusion of several elements into a new industry is, as such, not in the least surprising. In the very favourable climatic conditions of the second half of the Last Interglacial the population of Europe was conceivably fairly dense, (i.e. within the low density of population possible under a wild-food economy), and the co-existence of two or three cultural groups side by side must have encouraged cultural intercourse and exchange of ideas. It is remarkable, however, that the Levalloisians all the time maintained their cultural individuality, although they took over from the Acheulians the practice of making hand-axes, and so forth. They did not merge with the Mousterians either. But the Acheulians disappeared when the Last Glaciation began, whilst both Levalloisian and Mousterian proved to be adaptable to the cold climate. This raises again the interesting question why the hand-axe industries vanished from the scene when a periglacial zone developed (see p. 290).

In most parts of Europe, the Mousterian did not outlast the end of the first phase of the Last Glaciation. During the following interstadial, Aurignacian replaced it, except in some circumscribed areas where the Mousterian survived into LGl_2. North of the Alps, the only known area of this kind is Derbyshire, but the 'Pin Hole Mousterian' plainly contains an admixture of upper Palaeolithic elements.

Thus, we find that both Levalloisian and Mousterian varieties of the so-called middle Palaeolithic survived locally into the time of the spreading and establishment of the upper Palaeolithic. Measured

[1] Bowler-Kelley (1937, p. 15) suggests an interesting explanation for this difference: the raw material determined which technique, Levallois or Clacton, was used. At Le Moustier, where pebbles were used, the Levallois technique produced the largest possible flakes obtainable; at La Quina, however, the raw material, blocks of flint, did not enforce limitations in size of the cores, and the more wasteful, but simpler, Clacton technique was used.

in years, this survival was a considerable affair, some 30 to 40 thousand years.

In view of the association of Mousterian (and Levalloisian) with *Homo neanderthalensis*, and of the Upper Palaeolithic with *H. sapiens*, one is inclined to interpret this survival in terms of race. There is probably some truth in this, but both anthropological and typological evidence seem to indicate that absorption played a greater part in the process than did extinction (see p. 299).

Appearance of Aurignacian. In west and central Europe, middle and upper Aurignacian are present at the beginning of the second phase of the Last Glaciation. It is difficult to say for how long the middle Aurignacian lasted into this cold phase, since the evidence from Renancourt on the Somme (p. 173) is not unambiguous. In Palestine, it begins in the latter half of the interstadial and lasts to the climax of the pluvial phase corresponding to LGl_2. Its presence during the interstadial is further suggested by the Castillo cave. But it appears that, on the whole, upper Aurignacian took the place of the middle in most parts of Europe when and where the climate changed to the periglacial type early during LGl_2.

The Chatelperronian (lower Aurignacian) is datable in Palestine only, where it occupies the first part of the interstadial $LGl_{1/2}$. In Europe, it is known from few sites only and, since it precedes later Aurignacian, may well date from the same interstadial. But it may even be earlier than this, since there is no evidence with regard to its maximum age. The uncertain chronological position of the Chatelperronian in Europe obscures considerably the sequence of events during the crucial first interstadial of the Last Glaciation.

From the beginning of LGl_2 onwards, however, the archaeological succession is clear. It is a surprisingly rapid one. While the middle Aurignacian may have lasted into this time, upper Aurignacian or Gravettian dominates, both in the west (' western ' Gravettian) and in the east (Předmost or ' eastern ' Gravettian). When the loess phase of this glacial phase was at its climax, Solutrian appeared, north of the Alpine mountain chains, and in Spain. This was, at least in the major part of west Europe, a very brief invasion since, when the climate was still periglacial, the Magdalenian followed the Solutrian in many areas, especially in the west of Europe. In other areas, especially east of the Elbe, the Gravettian developed into an industry which is comparable with the Magdalenian in many respects. In the south, the Gravettian is replaced by the Grimaldian at the same time. When the climate improved, the Magdalenian, both in its typical, western, and its eastern variety, and the Grimaldian, persisted.

Rapid cultural changes during LGl_2. The changes in the industries which took place during the second phase of the Last Glaciation were indeed rapid. In this respect, the upper Palaeolithic differs

from the lower and middle. The typological change in 50,000 years of middle Levalloisian, for instance, is negligible. But all the changes just enumerated as occurring during LGl_2 took place within something like 10,000 years. It must have been a time of racial and cultural unrest, when at least three waves of migration reached Europe.

During the interstadial $LGl_{2/3}$, however, continuous evolution appears to have prevailed. The Magdalenian then ran its course, lasting altogether for not less than 50,000 years, and so did the other surviving upper Palaeolithic industries. When the third phase of the Last Glaciation reached its climax, all of them gave way to varieties of the Mesolithic, either by a gradual process of transformation, or by racial replacements. The former applies for instance to the Derbyshire caves, whilst the latter alternative is difficult to prove conclusively, since a sharp division in a section is often due to a hiatus during which the people lodged and developed in another locality.

Duration of some industries. It may be useful to compare, in tabular form, the durations of some of the industries, as they can be deduced from the absolute chronology of the Pleistocene. For a variety of reasons these figures must not be regarded as final, but as a picture of the present state of our knowledge they are, I think, of some value:

Industry	Approximate earliest and latest dates	Duration in years
Crag industries	? –540,000 B.P.	60,000 ys. or more
Abbevillian	540–480,000 B.P.	60,000 ys.
Acheulian	430–130,000 B.P.	300,000 ys.
Middle–Upper Acheulian (excl. Micoquian)	mid PIgl–mid LIgl	200,000 ys. or less
Clactonian (excl. Tayacian)	540–240,000 B.P.	300,000 ys.
Levalloisian	250–70,000 B.P.	180,000 ys.
Mousterian	140–70,000 B.P.	70,000 ys.
Aurignacian	*c.* 100–70,000 B.P. (longer in south)	30,000 ys.
Solutrian	*c.* 72,000 B.P.	very short
Magdalenian	70–20,000 B.P.	50,000 ys.
Mesolithic	20–*c.* 7,000 B.P.	13,000 ys.

Apparent dependence of certain cultures on climate. The hand-axe culture is, on the whole, confined to the mild phases of the Pleistocene. The same applies, apparently, to the Clactonian. The Levalloisian and Mousterian occurred in both mild and cold phases, but owing to the absence of hand-axe industries from the cold phases, they dominate in the latter. I venture to suggest that the reason for these differences lies in the ecological specialization of the cultures, the true hand-axe being an excellent instrument for digging

up roots, grubs, and other food from the ground, the Clactonian flakes with their strong cutting edges and many hollow scrapers being particularly suited for the working of wood, and the Levalloisian being essentially a hunter's culture, with a type of flake which would as a rule be admirably suitable for cutting and preparing carcasses. If one regards

the Abbevillio–Acheulians	as vegetable and grub gatherers
the Clactonians	as forest people
the Levalloisians	as hunters
the Mousterians	as hunters chiefly, who acquired some of the practices of the other groups

one is able to understand why the first two are essentially interglacial, and the last two both glacial and interglacial.

Outstanding events in the Palaeolithic chronology of Europe. The two most important events in the course of the European Palaeolithic are unquestionably (*a*) the introduction of the Levalloisian technique, and (*b*) the arrival of upper Palaeolithic man. It is, therefore, interesting to compare the chronological positions of these two events in Europe and in other parts of the world.

Mediterranean. The Mediterranean (see fig. 80, columns 'Northern Mediterranean' and 'Palestine') appears to provide the clue to several problems related to the spreading of the upper Palaeolithic. With regard to the lower and middle Palaeolithic it adds no chronological information to what is known from temperate Europe, except the suggestion that the Micoquian influence in the upper Acheulian appeared earlier in Palestine than in western Europe, namely at the end of the Penultimate Glaciation.

Last Interglacial. In Palestine, the Upper Palaeolithic appears as an admixture in the Acheulian and Levalloisian horizons during the Last Interglacial. Elsewhere in the Mediterranean area, and in temperate Europe, too, such upper Palaeolithic component is absent, though a few tool types which become prominent in the upper Palaeolithic, are found in the Mousterian (burins, for instance). The evidence from Palestine suggests that during the Last Interglacial upper Palaeolithic man was living, either in Asia (as suggested by Garrod), or in East Africa (as held by Leakey), and shows that the upper Palaeolithic peoples who invaded Europe after the first phase of the Last Glaciation, were members of a much older culture group than would be inferred from the European evidence alone.

LGl_1. During the first phase of the Last Glaciation, we find Levalloisian and Mousterian, and their varieties, everywhere. In this phase, the upper Palaeolithic component in the Palestine sequence had become rare.

Interstadial $LGl_{1/2}$. During the interstadial $LGl_{1/2}$, the middle Palaeolithic is much reduced, and by the end of this phase replaced

by some form of upper Palaeolithic in most localities. Mousterian appears to survive in middle Italy (as does the Levalloisian in northern France). The Chatelperronian is present in Palestine, and we may infer that the few western European localities of Chatelperronian also belong to this phase, though the possibility of a somewhat greater age cannot be excluded.

The Chatelperronian is not known from North Africa, nor has it been found in Italy. So far as the latter country is concerned, there is reason to believe that this absence of the true Chatelperronian is connected with the development of a local upper Palaeolithic. The Grotta Romanelli in southern Italy suggests that the Grimaldian was developing its characteristics as early as this interstadial, possibly influenced by some kind of Capsian (see p. 225). It would appear, therefore, that an Aurignacian stock, contemporary with the Chatelperronian, developed in Italy into the local Grimaldian variety of the Aurignacian, and that this process began during the first interstadial of the Last Glaciation. The faint indication of Capsian influence found by G. A. Blanc in the Terra Rossa of Romanelli might mean that the Capsian began as a similar, North African, development from an Aurignacian stock which had spread over the Mediterranean during the early part of the interstadial under discussion.

Thus, for the early part of this interstadial, one gains the impression of local developments of a primitive Aurignacian stock, while in some areas the Mousterian or Levalloisian was still surviving. The evidence from this phase is scantier than from the later ones, so that one might suspect that the density of population was much lower than during the later phases.

Later in the same interstadial, we witness the beginning of a remarkable period of migrations of upper Palaeolithic man. The first invasion of Europe was that by the middle Aurignacian, which occurred, presumably late, in the interstadial and possibly reached some places only at the beginning of LGl_2. Garrod (1938, p. 20) has shown that this invasion started from the east, perhaps the Iranian Plateau. In Palestine, the middle Aurignacian had a strong foothold and lasted definitely into LGl_2. Miss Garrod's admirable chart (1938, fig. 6) shows plainly that from Palestine and Anatolia, the middle Aurignacian localities extend across the Black Sea and north-westwards into central Europe, and thence westwards into France and Spain. This looks much like a geographically limited invasion by a people who worked north-westwards from the lands of the Black Sea, as did in later times the Danubians and other Neolithic tribes.[1]

It is very interesting to note that no middle Aurignacian is known from southern Italy. Instead, there is an abundance of

[1] This analogy was pointed out to me by Mr. Day Kimball.

Grimaldian, especially in Sicily. It was discussed and re-described by Vaufrey (1928) but is, unfortunately, not closely dated. It suggests that, while the middle Aurignacian invaders settled in Europe along the route outlined in the preceding paragraph, the Grimaldian continued to evolve from its ancestral stock in Italy.

In the whole of Italy there is only one locality with middle Aurignacian, at the Monte Circeo (Blanc, 1939*b*), but the section does not yet render accurate geological dating possible (see p. 241). This appears to be the southernmost point occupied by the middle Aurignacians, possibly an isolated one reached from southern France.

LGl$_2$. The second phase of the Last Glaciation witnessed so many changes that it is conveniently divided, though somewhat arbitrarily, into Period I (beginning of climatic deterioration, pseudo-pluvial), Period II (intensification of periglacial climate, passage to cold pluvial), Period III (climax of glacial phase, loess in temperate Europe, and cold-continental pluvial in Mediterranean), and Period IV (slight relaxation of the rigorous climate, immediately after III, initiating the conditions of the following interstadial).

LGl$_2$ *: P. I.*—No marked change in the industries has taken place, the middle Aurignacian appears to persist where it had established itself, while the Grimaldian continues in Italy.

LGl$_2$ *: P. II.*—Whilst in Palestine the middle Aurignacian continues, the Gravettian now replaces the middle Aurignacian in the whole of Europe with the exception of the Grimaldian province. The eastern Gravettian, characterized by its shouldered points and female statuettes (Garrod, 1938, p. 23; A. C. Blanc, 1938*d*) is plainly intrusive, but unlike the middle Aurignacian, this migration entered Europe from the Russian plains, passing north of the Carpathians, and gradually pushing through central Europe to France, with branches extending into the Grimaldian province (suggested by statuettes from Grimaldi and Savignano).

The western Gravettian, whose separate character is emphasized by Hawkes (1940, p. 31), is contemporary with the eastern Gravettian.[1] There is, so far, no suggestion of its origin, except that it cannot have come from Africa through Spain (Garrod, 1938).

LGl$_2$ *: P. III.*—During the maximum of LGl$_2$, the Solutrian intrudes into the Aurignacian sequence. It has been supposed that the Solutrian spread west from Hungary. This highly-specialized industry did not replace the Gravettian everywhere, and it had a very short life in those sites where it can be dated, since it had disappeared when P. IV began. Considering the close succession of migrational waves during LGl$_2$, it is conceivable that the Solutrian did not last much more than about 1,000 years. Though it extended

[1] Where 'eastern' influence is noticeable in the western Gravettian, it is in the upper, 'Font Robert' level only.

its realm temporarily to southern Spain, it did not enter the province occupied by the Grimaldian and kept to the north of the Alps.

In the south of Italy, a Capsian influence in the Grimaldian becomes more noticeable. This confirms that the Capsian was in existence at this time.

LGl_2: P. IV.—Immediately after the climax of LGl_2, when the climate was still periglacial in temperate Europe, the Magdalenian superseded the Solutrian in western Europe. As shown by Breuil in his classic work on the upper Palaeolithic (1912, 1937), it represents another wave of immigrants. The extreme adaptation to tundra and taiga exhibited by the Magdalenian suggests that it evolved in an area where these environments existed, though the absence from Europe of industries which might be ancestral to the Magdalenian indicates that this evolution took place farther east.

But typical Magdalenian did not appear everywhere in the periglacial zone. Scanty evidence from central Europe shows that upper Gravettian traditions survived and that industries of this type eventually changed, by convergence due to similar environmental conditions, into industries of Magdalenian facies.

In Italy, the Grimaldian continued. Locally, even a final Mousterian may have persisted. In Palestine, the middle Aurignacian was, by this time, replaced by the Atlitian which appears to have grown from the local middle Aurignacian by a process of hybridization with other upper Palaeolithic industries. No Gravettian or Grimaldian stage has been found in Palestine.

Interstadial $LGl_{2/3}$. During the interstadial $LGl_{2/3}$, we find an intensification of local evolution everywhere. The time of definite migration has apparently come to an end.

While the Magdalenian and its substitutes continued in periglacial Europe and in Spain until the maximum of LGl_3, the Grimaldian persisted in Italy. On the Riviera, temporary Magdalenian influence is recognizable, and the Capsian also appears to have contributed to increase the variety of industries, partly by introducing a microlithic element.

European and Mediterranean upper Palaeolithic. Conclusion. Surveying the upper Palaeolithic of Europe and the Mediterranean as a whole, we must admit that many problems, especially those of the sources of the Capsian, Chatelperronian and First Interstadial Grimaldian, remain unsolved. Apart from this, however, a fascinating picture of a Palaeolithic 'Age of Migrations' begins to reveal itself, when in close succession the middle Aurignacians, Gravettians, Solutrians and Magdalenians invaded Europe from the east, possibly all within a few thousand years.

North-west India. Since the correlation of the north-west Indian Pleistocene with that of Europe, based on the detailed chronology, is highly tentative, it must suffice here to point out that, provided

the suggested correlation is correct, the Early Acheulian would have appeared at the same time as in Europe (PIgl). The first traces of the Levalloisian technique would fall at the Penultimate Glaciation, presumably its first phase, and the Late Levalloisian would have been contemporary with the end of the Last Interglacial, again as in Europe. There is no obvious discrepancy in the Palaeolithic of north-west India and Europe. In particular, attention is drawn to the fact that the Levalloisian appeared at about the same time as in Europe.

South Africa. The correlation of South Africa with the northern hemisphere is even more tentative than that of north-west India with Europe. Taking it for what little it is worth, it would show that on the whole the cultures were somewhat retarded in South Africa. The pre-Stellenbosch stages would be contemporary with the Abbevillian of Europe. The Stellenbosch, however, would have caught up with Europe during the middle Pleistocene and thus have been largely contemporary with the Acheulian. The Levalloisian technique would, once more, have appeared in late middle Pleistocene times. The upper Palaeolithic would have had little influence in South Africa, even the latest Pleistocene industries being basically of Micoquian and Levalloisian tradition.

B. CHRONOLOGY OF EARLY MAN

(Fig. 81.)

Pithecanthropus-group. In the Pithecanthropus-group of the table, the Javanese finds have been combined with those of Sinanthropus from China. There is little doubt, after Weidenreich's studies (1943, &c.), that the two are so closely related that they can be regarded as geographical races of a single species [1] (Weidenreich, 1940, p. 377). This species should, according to the International Rules of Zoological Nomenclature, be called *Homo erectus* (Dubois), with the subspecies *H. e. erectus* (Dubois) and *H. e. pekinensis* (Black). *H. modjokertensis*, discovered by von Koenigswald (1936*b*), is a juvenile specimen of Pithecanthropus or *H. e. erectus* (Weidenreich, 1940, p. 376; 1943, p. 229). All these specimens are of lower Pleistocene age, though Pithecanthropus may just have lasted into the middle Pleistocene. The finds made up to the present, therefore, suggest that the Pithecanthropus-group of *Homo* is of great antiquity and that, to give a very rough date, it existed prior to 400,000 B.P.

A somewhat uncertain position is occupied by *Homo soloensis* Oppenoorth, which the author regards as belonging to the Neander-

[1] Unless one regards all fossil and recent men as forms of one species, as suggested by Weidenreich (1943, p. 276, no. 10). It is more convenient, however, to distinguish three, *H. erectus*, *H. neanderthalensis*, and *H. sapiens*, but biologically they are hardly more than 'good subspecies'.

thal stage, though he emphasizes at the same time that in the structure of the *sinus frontalis* it resembles Pithecanthropus sufficiently to make one think of a direct line of descent. Weidenreich (1943, p. 276) has developed this idea still further and regards *H. soloensis* as a link between Pithecanthropus and the modern Australoids. On palaeontological evidence *H. soloensis* has been allocated to the upper Pleistocene. This stratigraphical term, applied in the tropics, is inevitably very vague, but it may be noted that the Keilor Skull from Australia, which is *H. sapiens*, dates from the *early* upper Pleistocene and that its presence in the extreme south of Australia at that time suggests that *H. sapiens* evolved during the middle Pleistocene. This is, of course, confirmed by the Swanscombe Skull in Europe, but as regards the suggested position of *H. soloensis* between Pithecanthropus and the Australoids, there appears to be the difficulty of *H. sapiens* in Australia having been contemporary with, or even earlier than, *H. soloensis* in Java. In our table, *H. soloensis* has been placed in the Pithecanthropus-group in order to stress the affinities to his Javanese predecessor, but it must be left to the anthropologists to determine his real relationship either to this, the Neanderthal, or the *H. sapiens*-group.

Neanderthal-group. Little need be said about the Neanderthal-group of man. The age within the detailed chronology of most of the finds has been discussed by Zeuner (1940). All fall within the Last Interglacial and the first phase of the Last Glaciation, with the exception of the Steinheim Skull, the geological position of which is very uncertain, either late PIgl, or $PGl_{1/2}$ (the least likely), or LIgl. Another undated Neanderthaloid is the Rhodesian Skull (*H. rhodesiensis*), which cannot even be placed in one of the three major divisions of the Pleistocene.

No Neanderthal remains have yet been found which confirm his assumed association with the surviving Levalloisian and Mousterian *after* LGl_1.

The origin of the Neanderthal-group is as yet obscure. If the geological age of the Steinheim Skull were settled—and it would be possible to do so—we should at least know whether he, or his ancestor, lived in the middle Pleistocene. The only suggestion that *H. neanderthalensis* has his root in the lower Pleistocene is provided by the Heidelberg jaw, from the interstadial of the Antepenultimate Glaciation. This fossil is now regarded by Weidenreich (1936, p. 120; 1937) as a member of the Neanderthal-group. If this view is correct, the earliest Neanderthal man could well be the descendant of the Pithecanthropus-group.

Homo cf. *sapiens-group.* The view that *H. sapiens* is a late figure on the human stage is still held by some authors. The chronological evidence, however, though scanty for the early phases, does not support it.

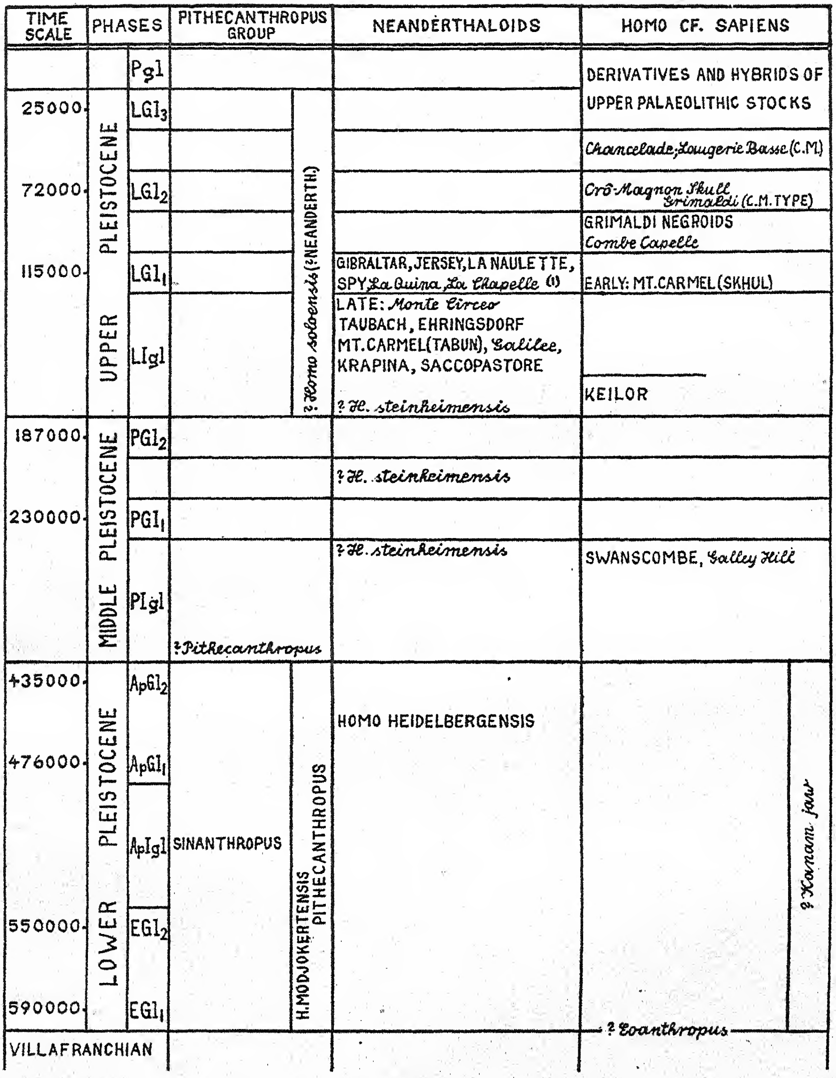


FIG. 81.—Chronology of Fossil Man. Tentative datings in *italics*. (1) Other Neanderthaloids tentatively referable to LGl: La Ferassie, Pech de l'Azé, Monte Circeo (second alternative).

From the lower Pleistocene, two fossils are known which might belong to *H. sapiens* in the wider sense. One is Piltdown Man (*Eoanthropus dawsoni* (Smith Woodward)), whose cranium is remarkably *sapiens*-like. The mandible, the human character of which is much disputed, and even denied (e.g., Weidenreich, 1936) should be left out of the discussion altogether, since it is uncertain whether it belongs to the skull or not. If the cranium is contemporary with the fauna (Hopwood, 1935, p. 50), Piltdown man would have lived just at the beginning of the Pleistocene and would in fact be the oldest human fossil. But the geological conditions in which the finds were made, are not unambiguous.

Similarly uncertain is the age of the Kanam jaw, the published records on which suggest a lower Pleistocene age.

In the middle Pleistocene, we are on safer ground. Swanscombe Man, dating unquestionably from the Penultimate Interglacial, is a member of the *sapiens*-group. This places the unjustifiably discredited Galley Hill Man, also from the 100-foot Terrace of the Thames (see Keith, 1929, p. 250 ff.) in a more favourable light, and Coon (1939) even makes him the prototype of middle Pleistocene *Homo sapiens*. There are other discoveries of skeletal remains of modern type from apparently middle Pleistocene deposits, which have not found acceptance largely because the experts did not expect to find *H. sapiens* in the middle Pleistocene.[1]

These cannot be resuscitated again, but Swanscombe Man alone is sufficient to settle the issue that *Homo* cf. *sapiens* existed during the Penultimate Interglacial, about 250,000 or more years ago. This makes him older than the entire datable Neanderthal-group, with the exception of the Heidelberg jaw.

The next younger representative of *H. sapiens* is the Keilor Skull from southern Australia, from the early part of the Last Interglacial. This recent discovery needs further geological confirmation, in view of its importance. It suggests, together with Swanscombe man, that *H. sapiens* was well established before he entered, or rather re-entered, the European scene at the beginning of the upper Palaeolithic.

In the light of this evidence, Mount Carmel Man is likely to be of the hydrid type. Keith and McCown consider him a form intermediate between *H. neanderthalensis* and *H. sapiens*, and discard the hybrid theory for lack of conclusive proof (see, for instance, McCown, 1936, p. 137). Since the time of their work, however, Swanscombe and Keilor Man have destroyed their argument that there is no 'certain evidence of the presence of Neanthropic Man in periods anterior to the end of the Pleistocene'. Coon (1939, p. 25, p. 38) regards the population of the Skhul cave of Mount

[1] One of these is Ipswich Man, found by Reid Moir and said to have lain underneath boulder clay (see Keith, 1929, p. 292).

Carmel as hybrids between the two types of man which existed at the time. This theory finds support in archaeological evidence.

The whole of Europe, however, and Palestine in part, appear to have been populated by more or less pure Neanderthal man, from the middle of the Last Interglacial to the end of the first phase of the Last Glaciation. Then, in the interstadial $LGl_{1/2}$, *H. sapiens* began to replace *H. neanderthalensis* in the whole of Europe, most evidently as the result of large-scale immigration. That *H. neanderthalensis* was not completely exterminated, but at least partially absorbed by the immigrants, has been shown by Coon on anthropological evidence (1939, p. 37), though this author thinks 'that the main accretion of the Neanderthal element took place farther east.'

It is very interesting to follow these waves of *H. sapiens* in the upper Pleistocene of Europe.

Upper Pleistocene Homo sapiens in Europe. Combe Capelle. The earliest remains of *H. sapiens* (apart from Swanscombe Man) are those associated with the Aurignacian industries. Coon (1939, p. 33) lists three specimens of the lower Aurignacian, (*a*) Combe Capelle, and (*b*, *c*) the two negroids from Grimaldi. The last two, however, are not earlier than middle Aurignacian, so that only Combe-Capelle Man remains, a scanty basis indeed on which to build conceptions of racial history. This specimen reminds Coon of Galley Hill in the type of its vault; it differs in many respects from the middle and upper Aurignacian specimens and is more akin to Recent man than is this intervening fossil group.

Grimaldi negroids. The negroid skeletons from the Grotte des Enfants, too, deviate from the majority of upper Palaeolithic men, but also from Combe Capelle. They show nothing of the robusticity and exuberance of bodily growth of Crô-Magnon Man, whose contemporaries they were.

These skeletons came from foyer I of the Grotte des Enfants. Originally, they were regarded as associated with lower Aurignacian, which view has been adopted by Burkitt (1925, p. 185) and Coon (1939, p. 33). But Vaufrey (1928, p. 108–9) states that the foyer K, *beneath* these skeletons, contains Aurignac bone points (à base fendue), burins busqués and lames à étranglement which are middle Aurignacian types. In the layers above, upper Aurignacian stone tools become abundant, and the bone tools rarer and atypical. For this Italian facies of the upper Palaeolithic, Vaufrey adopted Rellini's term, *Grimaldian.* It looks, therefore, 's'il y avait substitution au facies aurignacien occidental (Aurignacien *sensu stricto*) du facies italien de cette même industrie' (1928, p. 109).

This suggests that the negroids are not lower Aurignacian, but middle or upper. The fact that a skeleton of Crô-Magnon type was found in foyer H, where the upper Aurignacian tool types

become frequent, might indicate that the negroids here represent the middle Aurignacian, but this most certainly need not imply that all middle Aurignacians were 'negroids'. This question needs investigation after a careful typological allocation of the Aurignacian skulls which have so far been considered in bulk only by most anthropologists.

The precise age of the negroids appears to be late in the interstadial $LGl_{1/2}$, since Merck's Rhinoceros is found only in the deeper, Mousterian level (L), according to Obermaier, while the reindeer does not appear until foyer F, which is in the Grimaldian complex. Crô-Magnon man occurs immediately above the negroids, i.e., late in the interstadial or at the beginning of LGl_2.

The Grimaldi 'negroids' stand curiously apart from other men of Aurignacian age. Though their affinity to the negro stock is by no means certain, they indicate the presence of a race different from both Combe Capelle and Crô-Magnon, and unknown elsewhere in the Palaeolithic of Europe.

Crô-Magnon. Middle and Upper Aurignacian man [1] is well attested by about 35 skulls which all belong to the Crô-Magnon type. In this group, Coon has found evidence for the admixture of Neanderthal blood which he makes responsible for several of the properties of this race, such as its tallness, for instance. Whether the Crô-Magnon race appeared as early as in the mild interstadial $LGl_{1/2}$, or not until the climate turned cold at the beginning of LGl_2, is uncertain. Certain it is, however, that they were present by this time, not only in large numbers, but also in two different racial types, a dolichocephalic eastern or Předmost type, and a more broad-headed western type (Crô-Magnon proper). This early racial differentiation finds a parallel in cultural differences.

Magdalenian and later man. The Crô-Magnon type survived into the Magdalenian. But another type has been found associated with the Magdalenian, that of Chancelade, supposed to have eskimoid affinities. Since the Magdalenian was especially adapted to life in a cold climate, it has been suggested that Magdalenian and Eskimo are related, both racially and culturally (for instance, Morant, 1926, pp. 257–76). While the cultural resemblance, so far as it exists is believed by several authors to be the result of convergence, the racial affinity is still *sub judice*. Although there are several skulls from various localities which exhibit the eskimoid features (eversion of gonial angles, prominence of malars, flattening of part of facial plane), quite a number of true Crô-Magnon specimens have been found associated with Magdalenian (Laugerie Basse, for instance).

[1] Coon considers this group in bulk, together with Solutrian man, because the material was originally monographed by Morant (1930–1) in this form. Coon's conclusions are based on a re-consideration of Morant's extensive study of this group.

Coon (1939, p. 49) therefore concludes that during the Magdalenian, 'the internal diversity of Upper Palaeolithic European man became more noticeable than before. Some of the examples which are left to us represent a continuation of pre-existing Aurignacian forms. Others show a modification found among living peoples of the Arctic, while still others anticipate the size reduction of the Mesolithic.'

The intriguing feature of the Magdalenian is its long duration. The non-Mediterranean Aurignacian, so far as evidenced by human remains, covers the short period of some 10,000 or 20,000 years. The Magdalenian, however, was a matter of some 50,000 years, and during this time-span much of the development towards the Mesolithic and Postglacial racial distribution must have occurred.

Conclusion. The chronological distribution of early man does not conform with some of the current theories on the evolution of man. Since in selecting our evidence high standards of reliability have been applied, it may be said that, though the chronological arrangement cannot be regarded as infallible, it will require fresh evidence, and not merely arguments, views or inclinations, to dislodge substantially any one of the examples used.

One point is apparent from the table, that the evolution of *Homo* is not entirely confined to the Pleistocene. We find the definitely human Pithecanthropus-group in the lower Pleistocene, and there is some suggestive evidence for the *sapiens*-stock going back to this time. If this proves to be true, the *Homo*-stock as a whole must date from well within the Pliocene.

C. CHRONOLOGICAL ASSOCIATION OF HUMAN REMAINS WITH INDUSTRIES

For the sake of clarity, the tools and the skeletal remains of early man have been treated separately in the preceding parts of this chapter. It now remains to point out very briefly those instances in which a definite association of an industry or culture with a certain race is indicated by the evidence available up to the present. In doing so it will be necessary to bear in mind that the picture is liable to change as fresh evidence comes forth, and that, in this matter, we are very apt to favour, consciously or not, certain pet theories. The following account, therefore, does not enter into the discussion of theories; it is intended to present the evidence with which theories have to conform.

Pithecanthropus-group. The tools found with the fossils of the Pithecanthropus-group do not afford definite information on the cultural level. Only the implements from Choukoutien are plentiful enough to constitute an industry. Both lithic and bone components are atypical, and Pei (1939*b*) states that the tool types show affinities to the Clactonian, Tayacian, Mousterian and even upper Palaeolithic. Levalloisian technique appears to be absent, and it

could hardly be expected because of the poor raw material (quartz). All that can be said is—that it is a flake industry, and that no hand-axes are associated with it. This may well be significant, though the absence of hand-axes also could be explained by means of the poor raw material available.

Neanderthaloids and flake industries. Nothing whatever is known about the kind of man who made the Clactonian. Also, nothing is known about the lithic industry of *Homo heidelbergensis*. It is possible, however, that he used bone (see p. 157).

The Levalloisian group of industries is associated with *H. neanderthalensis* in Jersey (teeth only; middle-upper Levalloisian), and in the Mount Carmel Caves (Tabun, lower Levalloiso-Mousterian). This is scanty evidence indeed for the widely-held view that the Levalloisian was made by Neanderthal man.

The Mousterian, however, is undoubtedly, and apparently without exception, an industry of *H. neanderthalensis*. All the many specimens, both from the Last Interglacial and from the first phase of the Last Glaciation, which have been found together with implements, proved to be Mousterian, with the exception of the two mentioned above.

The final stages of the Mousterian and the Levalloisian which locally survived the first phase of the Last Glaciation, have not been found associated with human remains.

On this background of facts relies the theory that *H. neanderthalensis* was the man who produced the flake industries.

Homo sapiens and hand-axe culture. This theory is complementary to that which attributes the hand-axe industries to the *H. sapiens* group. There is only one locality which exhibits this association, namely, Swanscombe. The belief that the hand-axe industries *are* the work of *H. sapiens* has originated, so far as I know, in some arguments of Leakey (1936, p. 164, for instance), put forward in a cautious manner, that (*a*) *H. sapiens* must have been fully evolved by middle Pleistocene times, since otherwise there would have been no time for the evolution of the several races with which we are confronted in the upper Pleistocene, and (*b*) since the Levalloisian-Mousterian group was *H. neanderthalensis*, the hand-axe group should, *per exclusionem*, have been this early *H. sapiens*. It will be noticed that this argument does not rely on either Leakey's disputed fossils from Africa, or on any find positively proving the association (Swanscombe was not known yet at the time Leakey expressed this opinion). As a possibility, this theory should be regarded seriously, but it cannot be denied that two individuals discovered (Swanscombe and Galley Hill) do not yet justify sweeping generalizations.

H. sapiens and blade cultures. There is abundant fossil evidence that the upper Palaeolithic blade industries were made by *H. sapiens*.

This need not be illustrated by examples, but among the many which exist some provide more detailed information concerning the appearance of races of *H. sapiens* in definite association with certain industries.

Beginning with the earliest instance of this kind, the Mount Carmel Caves must be mentioned again. It will be remembered (see p. 289) that, during the Last Interglacial, the Acheulian as well as the overlying Levalloiso-Mousterian layers contain a conspicuous upper Palaeolithic component. In the lower Levalloiso-Mousterian of the Tabun Cave, *H. neanderthalensis* was found, but in the Skhul Cave, the numerous individuals cover the range from *H. neanderthalensis* to *H. sapiens*, though associated with the same industry. It is not unreasonable to suggest that the *H. sapiens*-component of this population has something to do with the upper Palaeolithic element present in the predominately Levalloisian industry.

In the Aurignacian succession which has been discussed repeatedly in this book, we find the following associations of races and industries, beginning with the earliest:

(1) Combe-Capelle Man with lower Aurignacian.

(2) Grimaldi negroids with middle or upper Aurignacian.

(3) Crô-Magnon Man with middle and upper Aurignacian, Solutrian and Magdalenian. Two races distinguishable.

(4) Chancelade Man with Magdalenian.

Group (3) is of particular interest since its physical characters have been ascribed to the admixture of some Neanderthal blood. Culturally, of course, there is no trace of a corresponding middle Palaeolithic component left, but the suggested survival of Levalloisian and Mousterian into the time of Crô-Magnon man renders more probable such racial admixture at a slightly earlier date.

Within the Crô-Magnon race, an eastern dolichocephalic and a western brachycephalic group have been distinguished. There is a corresponding cultural difference between the 'eastern' and 'western' Gravettian, and Hawkes (1940) favours the idea that the eastern group of man was the bearer of the eastern Gravettian.

Considering that, in the short period of a few thousand years we meet with five types of *H. sapiens*, two of which appear to possess some Neanderthal blood, one has to admit that the evolution of *H. sapiens* must have taken place much earlier than during the early phases of the Last Glaciation. Physically, Swanscombe Man confirms this, but culturally it raises the interesting question of the origin of the upper Palaeolithic. The two alternatives are:—

(*a*) The upper Palaeolithic evolved from the Mousterian, under the modifying influence of *H. sapiens*. This is to some extent supported by the existence of transitional cultures, such as that of Abri Audi. The intriguing factor, however, is Combe-Capelle Man, who is more *H. sapiens* than his successor, Crô-Magnon Man

(Coon, 1939). One would rather expect a racial transition, due to interbreeding, at the beginning of the upper Palaeolithic, if this theory were true.

(*b*) The upper Palaeolithic has a long history closely and exclusively associated with *H. sapiens.* Conclusive evidence for this is lacking, but some circumstantial evidence can be adduced. It consists, in part, of the evidence from Mount Carmel, and in part of the argument that both the Acheulian and upper Palaeolithic were *sapiens*-industries, and that the most primitive Aurignacian known (Kenya) can be derived typologically from the Acheulian by assuming a certain amount of borrowing from the contemporary Levalloisian (Leakey, 1934, p. 134).

New discoveries are necessary to decide which of these alternatives, or any new and unexpected ones, are right. It is not the purpose of a book on chronology to discuss problems of this kind, interesting though they may be.

PART IV

DATING THE HISTORY OF THE EARTH AND OF LIFE BEFORE THE ARRIVAL OF MAN

(Back to about 1,500 million years ago)

CHAPTER X

THE MEASUREMENT OF GEOLOGICAL TIME PREVIOUS TO THE PLEISTOCENE ICE AGE

Introduction. The preceding chapters have been devoted to the period of man's established presence on earth. This includes, geologically speaking, the Postglacial or Holocene, and the Ice Age or Pleistocene, both together constituting what is often called the Quaternary Period. The method of dating based on the cycles of solar radiation has suggested an age of at most about one million years for the beginning of the Quaternary, whilst it has appeared advisable to restrict this 'epoch' to the stratigraphically well-established record which starts about 600,000 years ago.

The Quaternary, however, is nothing but the terminal phase in the earth's history, and geologists have usually agreed that the duration of the known geological history of the earth must have been many times longer than the duration of the Quaternary. In order to set a wider chronological frame to man's existence on earth, we shall now proceed to consider the age estimates and determinations for the pre-Quaternary history of the earth and of life.

Stratigraphical succession. For this purpose it is essential to be acquainted with the main divisions of the earth's history. These are primarily based on the strata accumulated (and subsequently often dislocated, folded and broken up) in the course of time, either in ancient seas, or lakes, rivers, deserts or glaciated areas. The branch of geology dealing with these is called stratigraphy. The basic idea of stratigraphical work is the law of superposition, meaning that, unless displacements occurred after deposition, a layer (*b*) covering a layer (*a*) must be younger than (*a*). Thus, it has been found possible to establish a succession of strata from the earliest known to the latest.

A. PALAEONTOLOGICAL AND GEOLOGICAL 'TIME-KEEPERS'

It was further discovered that the fossilized remains of ancient animals and plants contained in the strata indicate changes of fauna and flora in the course of time. Many forms of life existed for comparatively short periods only and therefore afford valuable

guidance for the correlation of strata in distant places. On the whole, fauna and flora became increasingly similar to modern ones as time passed. Some problems connected with this phenomenon will be discussed in the final chapter ; here it is sufficient to note that the main divisions of stratigraphy are defined by the dominant forms of life contained. Thus, the eras are termed as follows: Azoic (lifeless) era, Archaeozic (primaeval life) era, Proterozoic (very early life) era, Palaeozoic (ancient life) era, Mesozoic (middle life) era, and Cainozoic (modern life) era. Those who are not familiar with the stratigraphical succession may gather further details from the accompanying tables (figs. 82, 83).

'*Clocks*' *or* '*Time-keepers*'. For the purpose of dating the geological past previous to the Ice Age, the 'clocks' or time-keepers used in the Quaternary are of little or no help. Of the cycles used in the Quaternary, tree-rings are obviously of no use. Varves have been counted in earlier periods, as described in chapter II (p. 36), but although they may give the duration of certain limited phases of the earth's history, they do not supply dates linked with the present day. Similarly the astronomical cycles which have been so successfully applied to the dating of the Pleistocene, no longer hold good for earlier times since, again, the continuity with modern times is lacking. They have, however, been used occasionally for estimates of duration, as in the case of the Cretaceous (Gilbert, 1895). Clearly, other clocks are required, preferably such as register very long time-units.

Some authors have considered organic evolution as a clock of this kind, others regarded the rate of accumulation of sediments as a trustworthy time-keeper, some relied on the gradual increase in the salinity of the oceans, others on the supposed gradual cooling of the earth. It was not until the radioactivity of minerals and rocks was discovered that a new and reliable way was opened for dating the stratigraphical succession and for estimating the minimum age of the earth. It is worth while to consider briefly the early attempts at dating, before describing the modern methods based on radioactivity. Those who are especially interested in the subject are recommended to read A. Holmes's excellent and easily accessible book on the Age of the Earth (1937). Other important publications treating of the geological aspects of the problem are by Walcott (1893), Barrell (1917), Lotze (1922), Holmes (1931), Knopf (1931), and Schuchert (1931).

The '*palaeontological clock*'. From the beginning of the Pleistocene to the present day, organic evolution was on a small scale only. Man himself did not change a great deal, considering his differences from the apes, and most of the modern mammals were present at the beginning of the Ice Age and have since undergone no more than minor changes. In such lineages of evolution as can

be studied, the result of 600,000 to 1,000,000 years of evolution is usually at most the forming of a new species (see p. 363).

The fact that during the Tertiary and earlier periods much greater changes in fauna and flora took place has suggested to geologists and palaeontologists that the duration of the earlier periods must have been infinitely longer than that of the Pleistocene.

ERAS	MILLION YEARS	SUBDIVISIONS
CAINOZOIC ERA		Subdivisions See Separate Table
	70	
MESOZOIC ERA		
	200	
PALAEOZOIC ERA		
	500	
PROTEROZOIC, PRECAMBRIAN, OR ALGONKIAN ERA		Penokean
	560	Keweenawan = Jotnian
	825	Huronian
ARCHAEOZOIC ERA		Algoman = Gothokarelian
		Sudburian or Temiskaming
		Laurentian = Svecofennian
	1300	Keewatin (Great Bear Lake) = Norwegosamian
	1550	Lower Black Hills Cycle = Marealbian
	1750	Manitoba Cycle
		?
AZOIC ERA		
ERA BEFORE FORMATION OF CRUST		
ORIGIN OF EARTH	?	

FIG. 82.—Table of eras. Those preceding the Palaeozoic are often collectively called 'pre-Cambrian'. The Algoman and Huronian subdivisions are possibly contemporary.

Several workers have attempted to arrive at figures on this basis, assuming that the rate of evolution was, on the whole, constant throughout time.

Lyell's estimate. Lyell (1867), one of the founders of modern geology, studied the changes in the shell-fauna during the Tertiary and compared them with the change that has taken place since the beginning of the Ice Age. He found that the Pleistocene covers not

more than one twentieth of the evolution which has taken place since the lower Miocene. The time from the lower Miocene up to modern times he regarded as one complete 'cycle of evolution', in the course of which all species existing at the beginning were replaced by new ones. He accepted Croll's figure of one million years for the Pleistocene. Accordingly, the lower Miocene is 20 million years old. Four cycles are said to have elapsed since the beginning of the Tertiary, corresponding to 80 million years. Adopting a similar way of finding the age of the Palaeozoic, Lyell considered 12 cycles as sufficient to cover the time from the beginning of the Palaeozoic up to the present day. This corresponds to 240 million years. Modern palaeontologists would assign more than 12 cycles to this space of time.

Allowing for the vagueness of Lyell's procedure, these estimates are surprisingly good, as is shown by the results of the methods based on radioactivity (lower Miocene about 30, early Tertiary about 70, early Cambrian about 450 million years).

Matthew's estimate based on the evolution of the horse. Matthew (1914) used the well-known lineage of the evolution of the horses as a measure for the duration of the Tertiary. Taking as a unit the changes in the anatomy of the horse from the first glaciation up to the present day, he found that about 85 times that measure must have elapsed since the early Tertiary (lower Eocene), or about 100 times that amount since the very beginning of the Tertiary. In order to transform this factor into years, Matthew relied on three quite unsatisfactory estimates by Wright, Walcott and Penck respectively. Had he known the figure of 600,000 years for the 'first glacial advance', he would have obtained the very good estimate of 60 million years.

Discussion of the palaeontological method. The instances of Lyell and Matthew may suffice to illustrate the 'palaeontological clock'. Their figures show that the working of this clock has not been so unsatisfactory as is generally believed. Strictly speaking, however, it is a relative time-keeper only, since the duration of the phases is given in multiples of a selected unit, usually the duration of either the Tertiary or the Pleistocene. The absolute figures arrived at are all based on the estimates or calculations of the duration of the Pleistocene.

Compared with the earlier formations, the Pleistocene was exceedingly short, and the practise of multiplying such small unit a hundred times or more is somewhat hazardous. Any initial inaccuracy is multiplied accordingly.

Moreover, the question may be raised as to how far the method of expressing in figures the steps of phylogenetic evolution is permissible and whether phylogenetic evolution has proceeded at an approximately equal rate all the time. Matthew's example may

serve to explain this problem. In estimating the evolutionary steps of the lineage of the horses [1] from the Eocene up to the Pleistocene, he expressed in figures the amount of anatomical change distinguishing each stage from that which preceded it. He accepted as a unit the difference between *Equus scotti* (beginning of Pleistocene) and *E. caballus* (Recent). The morphological difference between *Hipparion* (Pliocene) and *E. scotti* is regarded as ten times as great as that between *E. scotti* and *E. caballus.* In this manner, he arrived at the following figures:

Recent:	*Equus caballus*	
Early Pleistocene:	*Equus scotti*	1
Pliocene:	*Hipparion*	10
Upper Miocene:	*Merychippus*	10
Lower Miocene:	*Parahippus*	15
Upper Oligocene:	*Miohippus*	5
Lower Oligocene:	*Mesohippus*	5
Upper Eocene:	*Epihippus*	15
Middle Eocene	*Orohippus*	10
Lower Eocene:	*Eohippus*	10

These figures express the amounts of morphological alteration which occurred in unknown spaces of time. If one assumes that the rate of change in the morphology of organisms is practically constant, then these figures may serve as time coefficients and, knowing the duration in years of one of the steps, the duration of any other phase or of the entire period involved can be calculated. Matthew himself was quite positive, at least concerning his case: 'I have been impressed with the fact that they seem to have a fairly constant maximum rate of evolution. The rate of alteration in structures that are being changed adaptively to some changing environment or habit is fairly uniform, comparing one phylum with another.' But is one really entitled to generalize and say that the assumption made is correct?

There is abundant evidence that the rate of evolution is not constant. There were phases when certain groups of animals or plants changed very rapidly (so-called explosive evolution), and others during which the morphological characters remained almost constant for a very long time. This is bound to impair seriously the use of organisms in the determination of geological time. Only if (as was done by Lyell) a large number of widely different groups are considered simultaneously, such as entire faunas of formations, the differences in the various lineages might merge into an average rate. This is probably why estimates of geological time based on the evolution of organisms frequently do yield figures agreeing with those obtained by other methods.

[1] It cannot be discussed here whether the species of horses quoted by Matthew represent a genuine ancestral lineage or not.

As a matter of principle, however, the time-scale should be obtained by some non-biological method and then be applied to the evolution of organisms, in order to find out what the actual rate of evolution is and how it varies.

The 'stratigraphical clock'. A great many more age estimates have been based on purely geological observations. Some of them rely on the occurrence of rhythmic alternations in sediments, whilst others are based on the cumulative effect of certain geological processes. The first group comprises all methods using deposits of the varve type; they help to determine the duration of horizons, formations or periods, but except in the case of the Postglacial varves of Sweden, they do not link up with the present time, nor are they applicable to pre-Palaeozoic periods.

The second group of methods has not the drawbacks mentioned of the first, but, relying on cumulative effects which have to be measured under present-day conditions and then applied to the past, they suffer from the same difficulties as do the palaeontological methods just described. The most outstanding examples are those of the increase of the salt contents of the ocean, and of the total thickness of sediments deposited since the beginning of geological history.

Methods and results based on rhythmic deposits. Not infrequently, geological deposits exhibit an exceedingly regular, rhythmic alternation of two kinds of rock, such as sand and clay, or limestone and chert. Provided the thickness of the packets (called couplets) is sufficiently constant throughout the sequence, one is inclined to suspect that the alternation was caused by some regularly working, rhythmic force which favoured for some time the deposition of one kind of sediment, and then for some time of the other. If one can find the time-unit implied, the duration of the period of deposition may be obtained by counting the couplets.

Varved clay and other annual deposits. The most widely known example is the glacial varved clay with its periodicity of one year. This has been discussed in detail in the second chapter (p. 20), and it will be remembered that glacial varves enabled de Geer and others to establish a time-scale for the last ten or twenty thousand years before the present time.

Several other deposits of the rhythmic kind have been mentioned in the same chapter and a few may be recalled here.

Korn's investigation of annual varves of Palaeozoic age. A very striking example is provided by the Devonian and Carboniferous 'varves' of Thuringia, studied by Korn (1938). They were interpreted to be annual, and supposed to be due to seasonal fluctuations of rainfall. Korn counted the layers and studied in detail the major cycles corresponding to the sun-spot cycle (11·4 years) and others. He found—on the assumptions made—that the lower Carboniferous

from the top of the Devonian to the middle Viséan horizon lasted about 800,000 years, this being ½ to ⅔ of the entire lower Carboniferous of Thuringia.[1]

Marr's estimate of the Ordovician and Silurian. A similar count was carried out by Marr (1928) in the Bannisdale Slates of the Lake District in England. These are shales of Lower Ludlow (Silurian) age consisting of alternating layers of fine mudstone and sand, several per centimetre. Marr counted about 700,000 in the series, and assumed that the couplets were annual. By extrapolation he estimated the duration of the entire Silurian at 5½ million years and that of the Ordovician at 4 million years. Both estimates are undoubtedly far too low.

Bradley's study of the Eocene of Colorado. Another noteworthy succession of annual varves is that of the Eocene Green River Lake of Colorado, studied by Bradley (1929). Here, the varves are more reasonably taken to be annual and the oscillations within the varves seasonal. From the number and average thickness of the varves Bradley argued that the Green River epoch lasted about 6,500,000 years or, with due allowance for error, between 5 and 8 million years.

He then proceeded to estimate the duration of the entire Eocene, assuming a mean rate of deposition of one foot in 3,000 years and assuming that there are no important breaks in the succession in the region concerned. He arrived at a mean of 23 million years. This figure compares very well with the estimate based on radioactive minerals (Barrell's estimate, 23 ± 3 million years).

Gilbert's estimate of part of the Cretaceous. A cycle much longer than the annual one is supposed to have found expression in the Benton, Niobrara and Pierre beds of the Cretaceous of Colorado. They are composed of shales containing a varying amount of lime. There is, in particular, a regular recurrence of beds averaging about 18 inches in thickness, with a more calcareous and a more argillaceous portion. Gilbert (1895) used this succession to estimate the time required for its formation. He claimed that a rhythmic phenomenon of an astronomical character must have been responsible, and selected that of the precession of the equinoxes (21,000 years, see p. 136) as the most probable. In this way he found that the mentioned groups of the Cretaceous required about 20 million years to be deposited.

Methods and results based on the rates of denudation and sedimentation. The four examples of the labours of de Geer, Korn, Bradley and Gilbert are representative of methods depending on a definite time-unit, such as the year or the precession cycle, having found its expression in the deposit. In the examples which follow

[1] This extraordinarily low figure shows that considerable gaps must exist in the succession; otherwise it cannot be reconciled with the estimates based on radioactivity.

this time-unit is replaced by an annual average rate at which some process is going on. This average rate is, of course, deduced from present-day observations, and it is tacitly assumed to be applicable to the remote past. This may, or may not, be justified; more probably it is not. The results obtained in this way, therefore, are of little reliability, and the methods are largely of historical interest.

Dana's calculation. As early as 1876, Dana calculated the total thickness of the sediments laid down during the Cainozoic, Mesozoic and Palaeozoic respectively and, assuming that the average rate of deposition was approximately constant through the ages, he obtained the ratio of 1 : 3 : 12 for Tertiary : Mesozoic : Palaeozoic. In transforming this ratio into years, however, Dana had to use Thomson's antiquated physical estimate and arrived at only 36 million years for the Palaeozoic.

Walcott's estimate. Walcott (1893) studied the sediments of the Cordilleran Sea which occupied western North America during the Palaeozoic. He calculated the total thickness of its deposits and applied to it an average rate of deposition of one foot in 200 years. This rate is exceptionally high, and Walcott's figures are, correspondingly, too low. He found 17,500,000 years for the duration of the Palaeozoic and, applying a ratio of 12 : 5 : 2, 7 million for the Mesozoic and 3 million years for the Tertiary. Had he been able to base his estimate on 60 million years for the Tertiary, he would have obtained 570 million years for the beginning of the Cambrian. This shows that his ratio for the relative duration of the eras was comparatively accurate, as the last-mentioned figure agrees fairly well with the results of the radioactivity method.

Moreover, the average rate of deposition is generally considered to be slower than was supposed by Walcott. Barrell (1917) regarded 1,650 to 3,300 years per foot as a reasonable estimate for sedimentation in geosynclines. These rates would raise Walcott's estimate to about 227–454 million years, figures which, though low, are in fair agreement with the calculations based on radioactivity.

Goodchild's estimate. Goodchild (1897) assumed a very slow rate of deposition and arrived at the result that 704 million years had elapsed since the beginning of the Cambrian.

Sollas's estimate. A more elaborate attempt to uphold the chronological method based on sedimentation is that by Sollas (1919).[1] Somewhat arbitrarily, he chose the basin of the Mississippi as the prototype. The rate of *denudation* for all geological times was, according to Sollas, one foot in 2,400 years,[2] but the rate of *deposition* of material in the Gulf of Mexico is said to be ten times larger than the rate of denudation in the area of the Mississippi River. Sollas,

[1] For further work on these lines, see *Bull. nat. Res. Council*, Washington, **80**: Age of the Earth.

[2] The present-day average is one foot in 9,000 years.

therefore, believed in a very fast sedimentation (about one foot in 200 years), and his figures for the duration of the respective formations are very low. The total maximum thickness of deposits over the entire earth formed since the beginning of the Proterozoic is 335,800 feet or nearly 10 kilometres, and allowance has to be made for gaps in the succession. In all, Sollas came to 80 million years for the total including the Proterozoic.

Barrell's criticism of the methods based on sedimentation. Unfortunately, Sollas was influenced by the results of Joly's sodium method (see p. 314), and it is evident that he tried to adapt his figures to those obtained from the salt contents of the ocean. Barrell (1917) reviewed critically Sollas's and other attempts at dating the past with the aid of sediments and showed how futile they are in view of the many unknown factors which might have modified the result.

To begin with, there is the assumption that denudation and

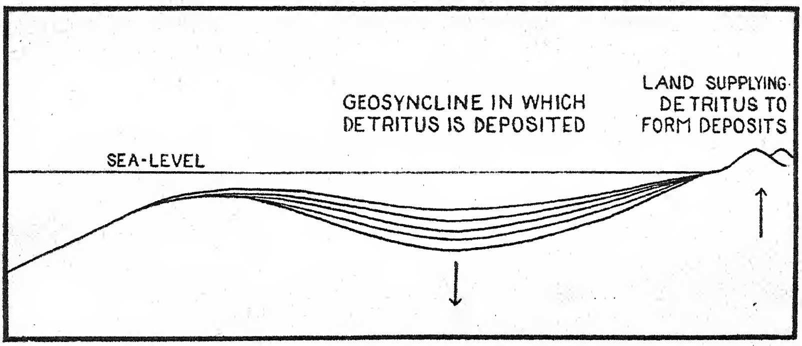


FIG. 84.—Schematic cross-section of a 'geosyncline', a zone of intense marine deposition with a sinking tendency of the sea-bottom (indicated by downward arrow). On the right, rising land is shown which supplies the material which gradually fills the geosyncline. Many geosynclines have land on both sides. Most of the present high mountains (Alps, Himalayas, Andes) are made up of sediments formed in geosynclines and later raised to great altitudes.

erosion proceeded in the past at the same rate as they do to-day. The present relief of the earth appears to be more varied and rougher than it was during the major part of the geological past, and the rate of denudation should, in the average, have been smaller than at present. This tends to increase the results obtained.

Furthermore, most geological deposits were laid down in limited, often trough-like areas in which the ground had a tendency to subside more or less rapidly (' geosynclines ', fig. 84). Whilst denudation of the surfaces above sea-level is practically general, deposition is restricted to certain zones, and the relation of the area of denudation to the area of the geosyncline in which it is laid down determines the rate of accumulation. This must vary from case to case, and it is dangerous therefore to generalize from one individual

case, such as the Gulf of Mexico of Sollas, or the Cordilleran Sea of Walcott.

Moreover, a fraction only of the material produced by denudation is deposited in the geosyncline on which the estimates rely. Much remains suspended or dissolved and is carried away and thus lost to observation.

These and other criticisms are discussed in detail in Barrell's paper, which also reviews all the important attempts made at calculating or estimating geological time. Perusal of this paper is highly recommended to all who are interested in the problem of dating the past by purely geological means.

Notwithstanding all the drawbacks and difficulties of these methods, the results for the duration of geological time since the beginning of the Palaeozoic are not entirely inconsistent, mostly varying around several hundred million years, an amount which has since been confirmed by the radioactivity methods.

Recently, Schuchert (1931) has once again studied the methods based on sedimentation, in order to find out whether they can be brought into line with the figures obtained from radioactive minerals and rocks. He admits that he himself was surprised at finding that there are 'easily enough marine strata since the beginning of Palaeozoic time to call for 500 million years'. For the whole of the Proterozoic he is inclined to allow 720 million years.

The salt of the ocean used for dating. A subtle though unsatisfactory method was conceived by the Royal Astronomer Halley (1656–1742), first applied by Joly (1900) and later elaborated by Sollas (1905, 1909). It is founded on the idea that all the salts contained in the water of the ocean are derived from the land, the water at the time of the condensation on the cooling surface of the earth having been, so to speak, distilled. Since then, weathering has released from the rocks a large amount of soluble matter and rivers have carried it into the ocean. The most important component is rock-salt, or sodium chloride, and its present total dissolved in the ocean is fairly accurately known. If it were known how much sodium chloride is annually released and delivered by rivers to the sea, a simple calculation would give an estimate of the age of the ocean.

With a view to simplification, calculations have been based on the chemical element sodium, instead of on sodium chloride. Joly found that 160 million tons of sodium are delivered to the sea every year, and that the quantity of sodium contained in the sea is at least 90 million times greater. Hence he concluded that the ocean is about 90 million years old.

Sollas, who regarded Joly's procedure with favour, was nevertheless compelled to apply certain corrections. For some time, he (Sollas, 1905) was inclined to reduce Joly's figure to as little as 30 to

40 million years, though in 1909 he accepted 80 million years as more probable. He also undertook to adapt to this figure the dates based on the rates of denudation and sedimentation.

Knopf (1931) and Holmes (1937) reconsidered Joly's method and came to the conclusion that it cannot provide more than a minimum age. Of the many objections to it, it may suffice to mention the principal one that, in order to supply the amounts of sodium alleged to be carried annually to the oceans, the rocks would have to lose more sodium than they had ever contained. Holmes concludes, therefore, that the amount of sodium added annually to the oceans is still imperfectly known. This and other objections show that the age of the ocean as suggested by Joly and Sollas is too low.

Quite recently, Spencer and Murata (1938) have once more studied the sodium method and, taking into account all the complications, arrived at the figure of 500 to 700 million years. This is still low compared with the results of the radioactivity method, though certainly in keeping with them.

Alleged cooling of the earth. The attempts at dating described so far have all aimed at establishing the age of eras and periods. In particular, the beginning of the Palaeozoic era has played an important part since it is the time when fossils first became abundant.

Sollas alone considered the Proterozoic as well which comprises the early stages of life up to the beginning of the Cambrian. Proterozoic, Palaeozoic, Mesozoic and Cainozoic together cover the history of life on earth and, since life depends on water of a temperature definitely below boiling point, the age of the ocean as such must be greater than that of the Proterozoic.

The estimates for the age of the ocean come in at this point. For most geologists and palaeontologists they appeared far too small, but for a time the authority of Sollas gave much support to the low estimates.

In addition, another calculation, apparently incontestable, suggested a probable age of less than 100 million years for the ocean since its condensation. This was the calculation of the age of the earth on the assumption that it had cooled down. Though the earth must have cooled down in the early phases of its history, there is no evidence of any further general cooling since life became abundant.[1] Still, the theory of gradual cooling was once universally accepted and it was Lord Kelvin (1883) who undertook to calculate, from the then available physical data, the time that has elapsed since the earth was in a molten state. He found 400 million years as the possible maximum and 20 million as the minimum, but

[1] Professor A. Holmes has pointed out to me that the fact that regions invaded by granite magmas have cooled to conditions like those elsewhere, might indicate that some cooling still takes place.

regarded about 100 million years as the most likely.[1] These figures were considered as too small by geologists, and a long controversy arose. Some tried to stretch the available values in order to make them match, but on the whole the weight of the physical arguments greatly hampered the advance of geological studies in absolute chronology. Yet, few geologists were ever inclined to accept such a short duration of the earth's history.

B. THE RADIOACTIVITY METHOD

Discovery of radium. At last, the physical estimate was upset by a series of discoveries which were connected with the now well-known element called radium and which revealed a source of heat compensating the cooling down. In 1895, Röntgen found that high-tension electricity in a vacuum-tube produces under certain conditions a kind of rays which, though allied to the light-rays, are capable of penetrating opaque matter to a varying degree. They influence, for instance, photographic plates through lightproof wrappings. These rays which have since become important in therapy, industry and mineral analysis, are called X-rays, or Röntgen-rays.

One may wonder how this discovery can have any bearing on the problem of *geological time*. The story is, indeed, one of a series of discoveries closely linked up with one another, and it provides a good example of the manifold interrelations of the various branches of science.

Radioactivity, discovery of radium. The X-rays appeared in a new light when, only a year later (1896), Becquerel observed that compounds of a heavy metal called uranium had the same chemical effect on a covered photographic plate as have the X-rays. Minerals containing uranium were studied in detail and, in 1898, Mme. Curie succeeded in isolating from pitchblende, a uranium mineral, a new element which possesses the quality of sending out rays in an immensely concentrated form. This element was named radium, and the phenomenon of the spontaneous emission of rays is called radioactivity.

Types of rays. It was Lord Rutherford who, in 1902, found that

[1] Some geological papers quote 40 million years as Lord Kelvin's estimate. This appears to be incorrect, unless a later publication by Lord Kelvin has escaped my attention. In 1883 (pp. 473 and 474), he purposely allowed very wide limits: 'If we suppose the temperature of melting rock to be about 10,000° Fahr. (an extremely high estimate), the consolidation may have taken place 200,000,000 years ago. Or, if we suppose the temperature of melting rock to be 7,000° Fahr. (which is more nearly what it is generally assumed to be), we may suppose the consolidation to have taken place 98,000,000 years ago. We must, therefore, allow very wide limits in such an estimate as I have attempted to make; but I think we may with much probability say that the consolidation cannot have taken place less than 20,000,000 years ago, or we should have more underground heat than we actually have, nor more than 400,000,000 years ago, or we should not have so much as the least observed underground increment of temperature.'

the radiation of radium and other radioactive elements consists of three kinds, called α-, β-, and γ-rays. If a small quantity of radium is embedded in a case of lead (which is one of the few substances not penetrated by the rays), with an opening permitting the rays to escape in one direction only, and is subjected to the influence of a strong magnet, the α- and β- rays are deflected as shown in fig. 85, whilst the γ-rays continue in a straight direction. The γ-rays were soon proved to be identical with the X- or Röntgen-rays, but the α- and β-rays are of a very different kind.

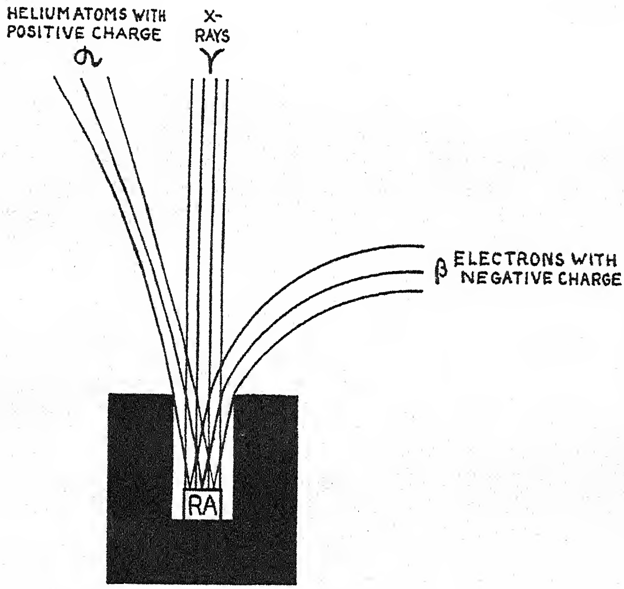


FIG. 85.—Radiation of radium under the influence of a magnet whose north pole is supposed to be in front of, and the south pole behind, the paper. The radium is encased in a block of lead which absorbs lateral radiation. The magnet diverts α-rays to the left, and the β-rays to the right. The γ-rays are not affected. —Modified, after Lotze (1922).

α-rays and production of helium. The α-rays have the smallest power of penetration, in air not more than a few centimetres. They consist of small particles ejected at a very high speed and charged with positive electricity. They are stopped by collisions with atoms of the surrounding matter from which they eventually pick up two negatively charged electrons each, which neutralize their positive electric charge. The result is that an ordinary atom of a gas called helium is produced. Thus, the startling discovery was made that atoms of one chemical element are formed by the decomposition of those of another.

As recorded by Holmes (1937), Lane has suggested a simple way of observing the radioactive formation of helium: 'Take your

wrist-watch or a compass that shines in the dark. After your eyes are made sensitive by sitting in a dim light for ten minutes, and then in darkness for a minute more, look at it with a good pocket lens. You will find it quivering with light. After a while, if your lens magnifies ten diameters or so, you will see that it is made up of countless sparks, like those from a bursting rocket. Each one of these represents the explosion of an atom, and the helium particle sent off, striking the sensitive zinc sulphide, makes it glow.'

Nature of the β-rays. Before following up this most important line, the β-rays have to be explained. They consist of electrons, minute negatively charged particles which, inside an atom, circulate around a comparatively heavy, positively charged core or nucleus, as planets do around the sun. The electrons constituting the β-rays travel much faster than α- particles, and their range is much greater.

Products of radioactive decomposition. It is evident that an atom of radium or some other radioactive element, emitting an atom of helium, cannot itself remain the same but must be transformed into something else. In fact, as radium decays, a gas called radium-emanation is formed which, in turn, emits another atom of helium and thereupon changes into a solid substance, called radium A. This process of emitting particles continues, however, and a succession of radioactive substances is formed until, finally, an inactive end-product is reached. This is lead. The succession of substances formed in the course of this process is depicted in fig. 86.

Moreover, the usual association of radium with uranium found an interesting explanation. Radium itself is produced from uranium as the parent-element via a number of intermediate stages. Thus, a long series of steps leads from uranium through radium to lead. The complete succession may be gathered from the diagram, fig. 87.

In this figure, the atomic weights are included, and it will be noticed that the atomic weight is reduced by 4 every time an α-, or helium-, particle is expelled. The atomic weight of helium is 4, and that of uranium 238. During the complete process of radioactive disintegration, 8 atoms of helium are emitted, after which the stable lead remains. This uranium-lead, therefore, has the atomic weight of $238 - 8 \times 4 = 206$.

The 'families' of radioactive elements. The disintegration series starting from uranium and leading, via radium, to uranium-lead with an atomic weight of 206, is called the uranium-family.

There are two other important families of radioactive elements, the actinium-family, and the thorium-family.

The actinium-family begins with actino-uranium, a variety of the ordinary uranium.[1] In the course of its disintegration, actinium

[1] Such varieties of elements which are distinguished by their atomic weights, but not by chemical qualities, are called isotopes. Another set of isotopes are the different kinds of lead, among them uranium-lead or radium G, actinium-lead, and thorium-lead.

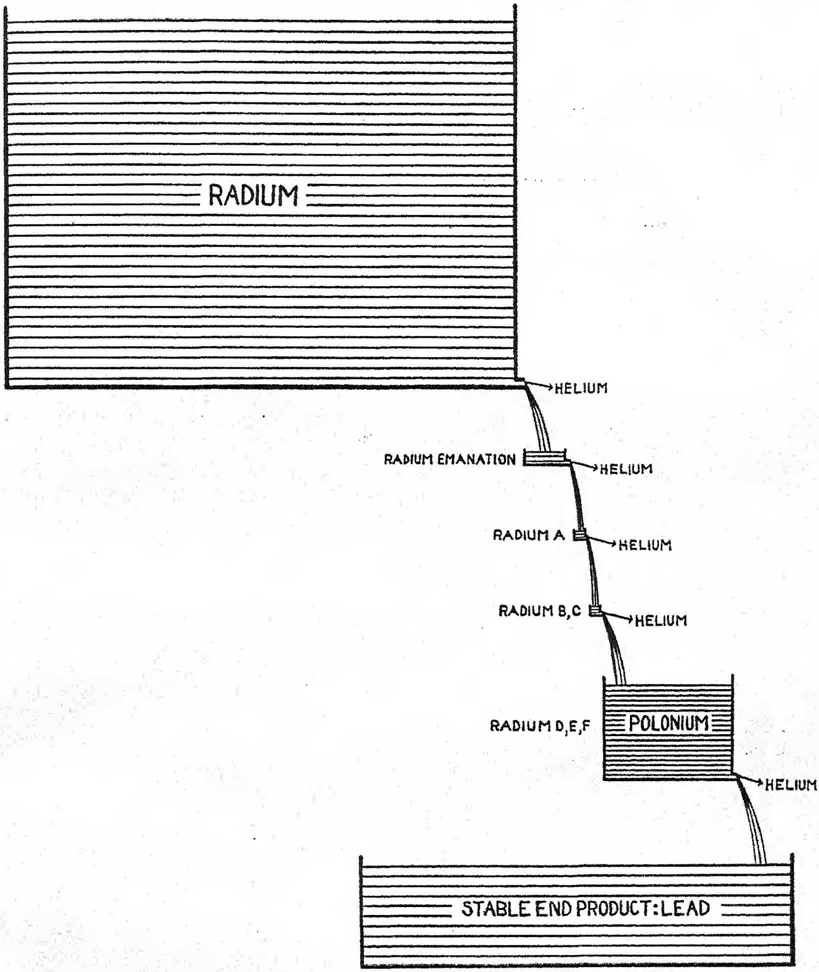


FIG. 86.—The disintegration of radium illustrated by means of a set of vessels (each representing a radioactive element), from which water is supposed to be running out (representing the atoms in the state of disintegration) and drops (representing helium) splashing off.—Modified, after Lotze (1922).

is produced, which in turn decays until finally, after the emission of 7 atoms of helium, the inactive end-product is reached, which in this case is actinium-lead with the atomic weight of 207.

The thorium-family begins with the element thorium (atomic weight 232). In the course of its disintegration, 6 atoms of helium are given off, and thorium-lead remains, with the atomic weight of 208.

The ordinary commercial lead has been found to be a mixture

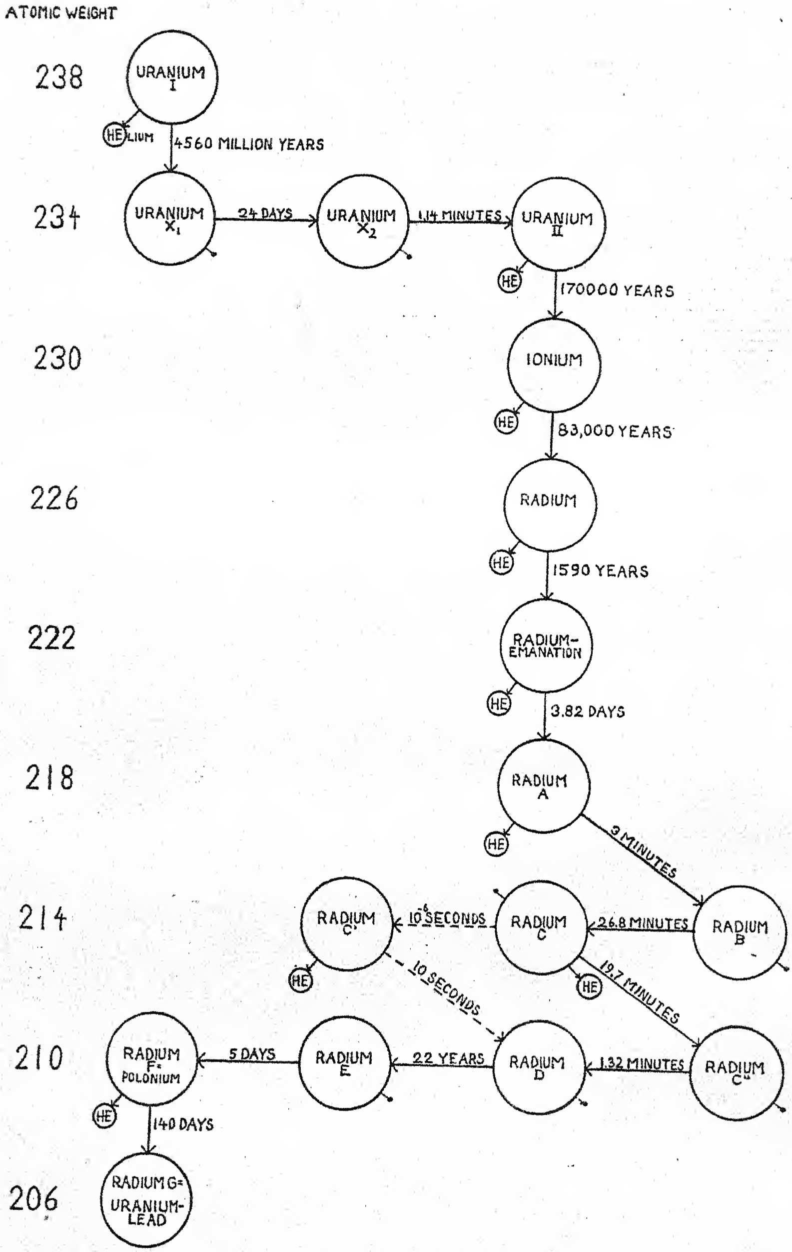


FIG. 87.—The disintegration of uranium. Each stage represented by a circle. Small circles show helium splitting off, small black dots electrons splitting off. The half-time periods are given beside the arrows connecting the stages. Each time a helium atom is given off, the atomic weight drops by four.

of the three varieties of lead mentioned (plus small quantities of others), and its average atomic weight is 207·21.

Half-life, or half-value, period. The time-rate at which the disintegration of a radioactive mineral proceeds is constant and determinable. This fact has opened new and most unexpected ways for the measurement of geological time. The time-rate varies enormously with the kind of element concerned, between a fraction of a second and several thousand million years.

One might expect that the time for the deterioration of an atom would depend upon its individual age. Taking a given quantity of radium, for instance, its atoms are known to have been formed out of ionium atoms by the loss of one atom of helium each (see fig. 87). Some atoms of radium are bound to be older than others, the process of transformation having continued for a long time. It is natural, therefore, to expect that those atoms of radium which were formed first would be, in turn, the first to decay again and to be transformed into radium-emanation. This is not the case, however, and it has been found that the disintegration of the atoms depends entirely on chance and not on their individual ages.

Accordingly, disintegration proceeds in such a way that, of the total number of atoms contained in a quantity of radioactive matter, a certain percentage is destroyed in every minute. After some time, only 50 per cent. of the original number of atoms will have survived, the others having been transformed into the next stage of the series of disintegration.

Thus, of 1 gram of radium, only $\frac{1}{2}$ gram will be left over after 1590 years, the other $\frac{1}{2}$ gram by then having changed into radium-emanation. After another 1590 years, $\frac{1}{4}$ gram of radium will have survived, after a further 1590 years $\frac{1}{8}$ gram, and so forth. The period of time required to reduce to one half a given quantity of a radioactive element is, therefore, called its half-life period, or half-value period.

The half-life periods of the members of the uranium-radium family are included in fig. 87.

Accumulation of helium and lead. It is evident that, under such conditions, helium and lead will be produced by any radioactive parent-element from the moment it came into existence. At first, the quantities were minute, but in the course of long periods of time, considerable quantities have been accumulated. Clearly, since helium and lead are produced (in uranium minerals) at the expense of uranium, the ratio of helium : uranium on the one hand,[1] and of uranium-lead : uranium on the other, must bear a fixed relation to the age of the mineral investigated. The half-life periods of all members of a series being known, it is possible to calculate the time

[1] It should be noted that helium is liable to escape from the specimen, see p. 329.

that has elapsed since the accumulation of lead began in the material under investigation. One million grams of uranium produce $\frac{1}{7,600}$ gram of uranium-lead per year.

Measuring time by the helium and lead ratios. For a good many reasons, which are too technical to be explained here, it is certain that accumulation of lead began with the moment of crystallization of the mineral. It is easy to understand, therefore, that not every radioactive material is suitable for age determination. In particular, sedimentary rocks laid down by water, ice or wind are, as a rule, unsuitable. The grains composing them are derived from earlier rocks (except in chemical sediments), have been affected by weathering and mechanical wear and, if there are any radioactive particles in them, these must of necessity be older than the deposit itself.

Suitable materials are therefore chiefly confined to the igneous group of rocks, i.e. those of magmatic origin. They are mostly crystalline, being composed of large or small crystals of a variety of minerals, all closely interlocked and formed when the liquid magma had cooled down sufficiently to solidify. Particles of radioactive minerals enclosed in such rocks started their work of time-keeping at the moment of crystallization.

Igneous rocks, volcanic group. It is now necessary to recall the fact that there are three main kinds of igneous rocks. Group (*a*), being the most spectacular, is the best known to the non-geologist. These are the extrusive, or volcanic, rocks, or lavas, which were (and still are) produced from volcanoes and open fissures. They spread over the ground in the neighbourhood of the eruption pipes or fissures and cover sedimentary and other deposits previously laid down. They might, in turn, be covered by sediments at a later time.

Since the stratigraphical subdivisions of the earth's history are almost entirely based on the succession of sediments and their contained fossils, a flow of lava intercalated between two horizons of known relative age might afford a means of dating in years the stratigraphical phase to which the beds belong, if suitable radioactive material is present in the rock.

One of the best-known volcanic rocks of this kind is basalt.

Plutonic rocks. Group (*b*) are the plutonic, intrusive, rocks. These have crystallized from bodies of magma injected into the upper zones of the crust. They did not reach the surface and, therefore, cooled much more slowly than did the spreads of lava on the surface. This caused structural differences, especially a greater size of the mineral grains, but on the whole the same type of magmatic material is known both as intrusive and as volcanic rock. Intrusive bodies of magma profoundly influenced the invaded rocks by heat, pressure and addition of substance (this process is called contact metamorphism). Regarding age determination, it is important to

note that rocks influenced in this manner must be older than the intrusion (fig. 88).

On the other hand, bodies of intrusive rocks are often laid bare in the course of time by weathering and denudation, and younger, sedimentary beds might have been laid down on the exposed surface.

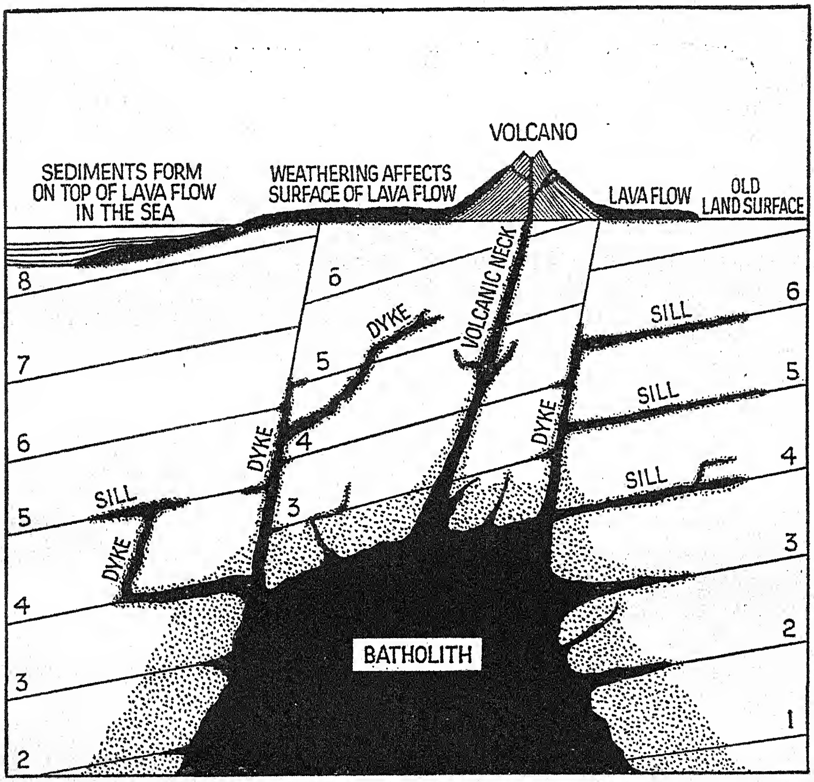


FIG. 88.—A purely hypothetical section to illustrate the chief modes of occurrence of igneous rocks, showing a body of magma of the shape called batholith, with dykes and sills emanating from it, and with a volcano on the surface. Contact metamorphism is indicated by dots. Sills have metamorphosed seams above *and* underneath, whilst superficial lava-flows metamorphosed the substratum only. Where lava flows are covered by later deposits, the latter will show no effects of metamorphism. This provides a means of distinguishing flows and sills in geological sections. The intruded sediments are numbered from the earliest upwards. The middle portion is shown uplifted between two faults.

Such deposits will of course show no traces of contact metamorphism, and this affords a means of establishing their age relative to the intrusive body.

If radioactive minerals are present in the intrusive rock, its age might be determined and valuable light thrown on the ages of the

surrounding and covering beds of sediments. In practice, suitable radioactive material is far more common in the plutonic intrusive rocks than in rocks of groups (*a*) and (*c*).

The most widely known kind of intrusive rock is granite. Granites of the Canadian Shield have supplied some of the early dates for the pre-Cambrian eras, ranging from 750 to 1750 million years.

Sills, dykes, and mineral veins. Group (*c*) comprises the minor injections in the form of dykes and sills (fig. 88). Magma which has penetrated into the bedding-planes of the surrounding rock, will form comparatively thin sheets of intrusive material there, and such structures are called 'sills'. If, however, the magma penetrated into a crack or fissure of the surrounding rock, cutting across bedding-planes, it is called a 'dyke' (pl. XX, fig. B).

The geological relationship of dykes and sills to the older and younger rocks associated with them reveals their stratigraphical age. Consequently, if radioactive minerals contained in a dyke supply a date for it, valuable information is gained regarding the age of the strata formed before and after the intrusion.

Mineral veins are often associated with granites and other plutonic bodies, but quite often they appear to be independent, and their origin is unknown. They are important from the present point of view, since certain radioactive minerals are found in them. Pitchblende (oxide of uranium) may be quoted as an example. From specimens of pitchblende, found at Joachimsthal in Bohemia, Mme. Curie succeeded in isolating radium in 1898.

The preceding excursion into geology is intended to show how radioactivity can help in the dating of sedimentary rocks which, themselves, do not contain radioactive minerals. But it is now apparent that, for the purpose of geological dating it is essential to know the exact position within the stratigraphical succession of the radioactive mineral to be analysed. This condition considerably restricts the amount of material available for the absolute dating of geological formations.

Lead-ratio used for dating. Let us now assume that we have obtained a radioactive material whose stratigraphical age is known, such as for instance a specimen of pitchblende from the lower Permian of Joachimsthal, Bohemia. There are two ways open for determining its age (at least in theory), one with the aid of the accumulated lead, the other with the aid of the accumulated helium.

Considering first the lead method, we know that one million grams of uranium produce about $\frac{1}{7,600}$ gram of lead per year. If the amount of lead present in the specimen is Pb^U, and that of uranium, U, then the time that was required for producing the

amount of uranium-lead present, in other words the age of the mineral, is

$$\text{age} = \frac{Pb^U}{U} \times 7{,}600 \text{ million years.}$$

Pb^U/U is a 'lead ratio'; for our sample of pitchblende it amounts to 0·03, corresponding to an age of 225 million years.

Correction for thorium and thorium-lead. Fortunately, our sample contains practically no thorium which, as we have seen (p. 318), is another important radioactive parent-element. Were we investigating a sample of material containing thorium beside uranium, then the lead determined would be uranium-lead plus thorium-lead, and an allowance would have to be made for the thorium associated with the uranium (see, for instance, Keevil, 1938).

Now, one gram of thorium-lead (Pb^{Th}) is produced by one gram of thorium in 21,100 million years. A pure thorium mineral, therefore, complies with the formula,

$$\text{age} = \frac{Pb^{Th}}{Th} \times 21{,}100 \text{ million years.}$$

For a reason which will at once become apparent, let us substitute for 21,100 the fraction, $\frac{7{,}600}{0{\cdot}36}$. The age, based on thorium and thorium-lead, will then be

$$\text{age}^{Th} = \frac{Pb^{Th}}{Th} \times \frac{7{,}600}{0{\cdot}36} \text{ million years.}$$

For a material containing both uranium and thorium, the age is, of course, the same, whether based (*a*) on uranium and uranium-lead alone, or (*b*) on thorium and thorium-lead alone, or (*c*) on uranium + thorium and the total of both kinds of lead. The age, therefore,

$$= \frac{Pb^U}{U} \times 7{,}600 \text{ million years}$$

$$= \frac{Pb^{Th}}{Th} \times \frac{7{,}600}{0{\cdot}36} \text{ million years}$$

$$= \frac{Pb^U + Pb^{Th}}{U + {\cdot}36Th} \times 7{,}600 \text{ million years.}$$

Lead-ratio. In practice, the analyst measures the total amount of lead present, and the expression $\frac{Pb^{total}}{U + 0{\cdot}36Th}$, accounting for the presence of both uranium and thorium, is the one which has to be determined in every case. It is called the 'lead-ratio'.

Allowance for wearing-out of parent-elements. In the preceding consideration three simplifications are implied which have to be allowed for.

Firstly, the fact has not been allowed for that the initial quantity of uranium and thorium was greater than that found by analysis to-day, since some of it has been destroyed by radioactive disintegration. Correction for this leads to a logarithmic formula which is too complicated to be explained here. In practice, the corrected values may be plotted against the ordinary values of the lead-ratio and graphs designed in which the corresponding lead-ratio (and age) can be read off directly.

Correction for actino-uranium. Secondly, the possible presence of the third parent-element, actino-uranium (p. 318), has so far been neglected entirely. This is an isotope of the ordinary uranium, the parent-element of the uranium-radium family. To distinguish ordinary uranium from its isotopes, it is called uranium I, and we shall henceforth use this term. In chemical analyses, the total of all isotopes of uranium is obtained, i.e. of uranium I as well as of actino-uranium.

Holmes (1937, pp. 150–5) has paid special attention to the problem of accounting for the presence of actino-uranium. It is known to disintegrate more quickly than uranium I. Fortunately, the quantities of actino-uranium and its descendants encountered are not large, and its influence on age-determination becomes appreciable in very old material only.

On the basis of the present, still somewhat scanty, knowledge of the actinium-family, Holmes has calculated provisional correction tables which, though they cannot yet provide perfectly accurate values, improve the dates obtained with the ordinary lead-ratio and bring them more closely into approximation with the real figure. Owing to the more rapid disintegration of actino-uranium, the corrected values are smaller than the uncorrected. This is how, according to Holmes, age-figures are affected by the provisional correction:

Age calculated from logarithmic formula	Age corrected for the maximum effect of actino-uranium
100 million years	96·5 million years
500 ,, ,,	478 ,, ,,
1,000 ,, ,,	933 ,, ,,
1,500 ,, ,,	1,350 ,, ,,
1,800 ,, ,,	1,570 ,, ,,

Accordingly, the age of our sample of lower Permian pitchblende (logarithmic formula, 225 million years) would have to be reduced, but even the probable maximum effect of actino-uranium would not reduce it to less than 220 million years. One notices that within the approximately 500 million years that have elapsed since the beginning of the Cambrian, the correction affects the results only slightly. It becomes more important in the Proterozoic and earlier eras of the earth's history.

In the table given further on, Holmes's corrected values have been used beside the uncorrected ones.

Difficulty of presence of initial lead. Finally, one more difficulty must be dealt with. So far, we have assumed that all the lead contained in a sample is lead produced by the disintegration of radioactive elements. This is not always the case, and volcanic rocks especially often contain much more lead than can ever have been generated from the radioactive substances present in them. As an example, Holmes (1936) quotes the famous basalt of the Giant's Causeway of Antrim which poured over the surface of that area in early Tertiary times. Even if the material had existed for as much as 1,600 million years, he says, the accumulated radiogenic lead could not have amounted to more than one eighth of the quantity of lead present and, considering the real age of this rock, this quantity is 300 to 400 times as much as can have been generated within the lava since it cooled down and became a basaltic rock.

It is obvious that, in cases like this one, the magma had been supplied with a varying amount of initial lead from other sources. The analytical practice of determining the lead-total will, in samples from such materials, inevitably catch the initial lead as well as the radiogenic lead. It is not impossible to get over this difficulty. The determination of the atomic weights of the kinds of lead present, for example, will help in calculating the amount of initial lead present.

On the whole, however, materials containing initial lead in appreciable quantities are awkward to interpret and often unreliable. Fortunately, the presence of initial lead is no obstacle to the application of the helium method for which volcanic rocks are often particularly suitable, for reasons to be explained later.

If, on the other hand, the amount of radioactive minerals contained in a sample of rock considerably exceeds the amount of lead, the chances are that the quantity of initial lead is comparatively small, and corrections based on mineralogical analysis and determination of atomic weights can be applied more easily. The rich uranium- and thorium-ores, which have supplied a great number of important age estimates, are in this category.

Summary of lead-method. Moreover, the larger the number of samples investigated, the more will the reliability of results increase. Samples taken from the same complex of rocks are likely to be of approximately the same age. The lead-ratios of specimens with a relatively large amount of uranium and a small amount of lead are likely to yield the best results, and if it so happens that minerals occur which are rich in uranium beside others rich in thorium, and both yield consistent age estimates, then these may safely be regarded as satisfactory.

Further, the relative ages in the stratigraphical succession of the

investigated materials are known, and the age estimates based on their radio-activity must be consistent with this succession. This provides another valuable check for the results.

In short, the application of the lead method has to be accompanied by a careful scrutiny of the chances of possible errors, and samples have to be selected accordingly. It is not surprising, therefore, that the number of really trustworthy age estimates is not very large, though it is continually increasing. A few are given in the following list (selected from Holmes, 1937):

Mineral	Relative age	Lead-ratio	Age, corrected for Actino-uranium (uncorrected values in brackets)
Uraninite, Mexico	Upper Tertiary	0·0046	33·5 million years (35) ,, ,,
Pitchblende, Colorado	Late Cretaceous	0·009	69·5 ,, ,, (72) ,, ,,
Ishikawaite, Japan	Jurassic	0·017	123 ,, ,, (128) ,, ,,
Pitchblende, Bohemia	Lower Permian	0·03	220 ,, ,, (225) ,, ,,
Pitchblende, Silesia	Lower Carboniferous	0·0377	269 ,, ,, (280) ,, ,,
Various minerals, Connecticut	Late Devonian	0·039	278 ,, ,, (290) ,, ,,
Uraninite, Massachussetts	Ordovician	0·049	349 ,, ,, (363) ,, ,,
Kolm, Sweden	Upper Cambrian	0·0574	405 ,, ,, (422) ,, ,,
Uraninite, Ontario	Huronian	0·109	743 ,, ,, (778) ,, ,,
Bröggerite, S.E. Norway	Huronian	0·129	854 ,, ,, (910) ,, ,,
Fergusonite, Stockholm	Laurentian	0·151	1,012 ,, ,, (1,065) ,, ,,
Samarskite, Colorado	Laurentian	0·152	1,050 ,, ,, (1,090) ,, ,,
Pitchblende, Great Bear Lake	(Keewatin) Great Bear Lake Cycle	0·228	1,387 ,, ,, (1,550) ,, ,,
Uraninite, N.E. Karelia	Marealbian Cycle	0·281	1,610 ,, ,, (1,890) ,, ,,
Monazite, Manitoba	Manitoba Cycle	0·259	1,750 ,, ,,

Helium method. Apart from lead, helium is generated by radioactive disintegration. Helium is a gas. Before its presence on the earth was established, it had been discovered in the spectrum of the sun, hence its name.

Were there not certain difficulties connected with the gaseous nature of helium, age estimates could be carried out with the helium generated by radioactive substances just as well as with the lead. The amount of helium present is determined and compared with the amount of uranium (and thorium) contained in the mineral, in other words, the helium-ratio is determined. Its formula (compare lead-ratio, p. 325) is

$$\text{age} = \frac{\text{He}}{\text{U} + 0{\cdot}27\text{Th}} \times 8{\cdot}8 \text{ million years.}$$

For convenience, the amount of helium is usually expressed not in grams but in cubic centimetres at normal temperature and pressure.

The principles of both the helium and lead methods being the same, we can confine ourselves here to pointing out certain practical difficulties of the helium method.

Loss of helium in the rock. It is obvious that lead, being a solid substance, is less likely to escape from a rock than helium-gas. The helium generated by a radio-active mineral will accumulate close around it in the rock, but in the course of the millions of years involved, some of it is bound to escape through cracks or along the boundaries of crystals. This loss will be comparatively small in a dense rock, but it will be large—

(*a*) if the structure of the rock is coarse enough to allow of diffusion of the gas;

(*b*) if the amount of generating uranium is large and, therefore, the quantity of helium so considerable that it is enclosed in the rock under great internal pressure;

(*c*) if the rock has been subjected to metamorphosis by heat or pressure which would both help to eject gases contained in it, and

(*d*) if the rock has been affected by atmospheric weathering, which would release the gas by loosening the texture of the rock.

To these has to be added the technical point that in pulverizing and otherwise treating the sample for analysis, more helium is inevitably lost.

Regarding (*a*), it is possible to select rocks which are fairly dense, but an allowance has to be made in any case. A mineral, which is considered to have a particularly high helium-retentivity, is magnetite.

Regarding (*b*), it is evident that materials with large amounts of

radioactive minerals will contain large quantities of helium. These will be under considerable gaseous pressure and, therefore, a greater quantity of helium is likely to escape. For this reason, it is advisable to select rocks with a small percentage of radioactive matter.

Regarding (*c*), it goes without saying that any material suspected of having been altered by metamorphosis should be discarded.

Regarding (*d*), this difficulty can be overcome by carefully selecting fresh specimens which, under the microscope, show no signs of alteration of minerals by weathering.

Minimum-ages by helium-method. In short, even if one selects samples with the utmost care, one can be almost certain that some of the helium is lost, and the age estimate obtained will be lower than the actual age of the material. On the other hand, Keevil (1941) reports that occasionally an excess of helium is found the source of which has not yet been discovered.

Results of the helium method. The early results of the helium method were, therefore, little satisfactory, and the discrepency from those of the lead-method was formidable. In more recent years, technical improvement of the helium-method appeared to lead to age-determinations which approached those of the lead-method closely but, unfortunately, it was found in 1937 that the helium-ratio had been based on a faulty radium standard (Evans, Goodman, Keevil, Lane and Urry, 1939; Urry and Holmes, 1941, p. 45).

This discovery has resulted in a critical study of the earlier helium determinations and in the development of new and better methods both of analysis and calculation. More than 350 determinations have been studied by Keevil (1941). Although this author found that the ratio of measured age to expected age varied between one hundredth and 25, he was able to show that the helium retentivity can perhaps be expressed eventually as a function of the various factors which cause the loss (*a* to *d*, above), in such a form that the method might be rendered more reliable. Keevil provides some interesting graphs showing the dependence on the kind of rock (granitic and basic rocks, porphyries and lavas), and on the stratigraphical age. The chances of the helium-method are not at the present considered as good by Keevil, but other authors who of course agree with Keevil as regards the difficulties, are less pessimistic.

Urry and Holmes (1941), for instance, emphasize that the sequence of the new helium ages is still found to correspond to the stratigraphical ages of the samples, although the figures in years are lower than those based on the lead method. In a revised helium-method time-scale these authors have computed results from a number of crystalline rocks, as follows:

Rock type and locality	Relative age	'Helium age'
Basalt, S.E. Oregon, U.S.A.	Pliocene	8 million years
Basalts, Flows in Douglas Creek and Columbia River Canyon, State of Washington, U.S.A.	Miocene	10 ,, ,,
Basalts, Lower Silesia	Oligocene	20 ,, ,,
Granodiorites, &c., Grass Valley, California	Cretaceous-Jurassic	60 ,, ,,
Dolerite sill, New Haven, Connecticut, U.S.A.	Triassic	93 ,, ,,
Dolerite sill, Palisades, New Jersey, U.S.A.	Triassic	100 ,, ,,
Basalt, Cape Spencer Flow, Nova Scotia, Canada	Triassic	100 ,, ,,
Basalt, Oldest Flow of Watchung Mt., New Jersey, U.S.A.	Triassic	105 ,, ,,
Monchiquite dyke, Riasg Buidhe, Isle of Colonsay, Scotland	Post-Torridonian probably Permian	125 ,, ,,
Biotite-monchiquite dyke, Kilchattan, Colonsay	Post-Torridonian, probably Permian	130 ,, ,,
Analcime-olivine-dolerite, Clee Hills, Shropshire	Upper Carboniferous	135 ,, ,,
Olivine-basalt, Little Wenlock, Shropshire	Lower Carboniferous	140 ,, ,,
'Newbury Volcanic Rock', Rowley, Mass., U.S.A.	Devonian	180 ,, ,,

It will be seen that the specimens from the Tertiary have yielded estimates which deviate but little from the lead-ages found for the subdivisions of the Tertiary, and that the divergence becomes the greater the older the specimen is on the relative time-scale. This illustrates well the fact that the loss of helium is, among other factors, a function of the geological age of the rock.

It will not be an easy matter to devise corrections for this helium loss, especially since the retentivity of the rock and the method of taking and analysing the sample introduce further losses which are even more difficult to assess.

Goodman (1942) however (also Hurley and Goodman, 1941) considers that certain minerals, such as magnetite, provide a much more reliable material than do rocks composed of several minerals. He states that a series of magnetites ranging stratigraphically from pre-Cambrian to mid-Tertiary, showed with few exceptions the proper age-sequence. The following list is in part extracted from

his diagram (1942, fig. 5) and in part taken from Hurley and Goodman (1941). It shows that his magnetite values do not compare badly with the lead time-scale.

Magnetite from	Relative age	Helium age ' about
Chespeake Mine, Utah, U.S.A.	Miocene	20 million years
Black Magnetic Mine, Utah, U.S.A.	Miocene	37 (30) ,, ,,
Stoddard Mine, Colorado, U.S.A.	Early Tertiary	50 ,, ,,
Fierro, New Mexico, U.S.A.	Early Tertiary	59 ,, ,,
Prince of Wales Is., Alaska	Cretaceous	81 (60) ,, ,,
Lynn Valley, British Columbia	Early Cretaceous	88 (100) ,, ,,
Texada Is., British Columbia	Jurassic	103 (120) ,, ,,
Cornwall, Pennsylvania	Triassic	126 ,, ,,
Gerrish Mt., N.S., U.S.A.	Jurassic-Triassic	128 (135) ,, ,,
Goose Ck., Virginia, U.S.A.	Jurassic-Triassic	137 ,, ,,
Boyerton, Pennsylvania	Jurassic-Triassic	133 (150) ,, ,,
Lakeville, N.S., U.S.A.	Jurassic-Triassic	135 (160) ,, ,,
Trun, Spain	? Carboniferous	230 ,, ,,
Magnitnaya, Urals	Carboniferous	300 (260) ,, ,,
Ducktown, Tennessee, U.S.A.	Devonian	260 ,, ,,
Vysokaya, Urals	Devonian	316 ,, ,,
Blagodat, Urals	Devonian (?)	366 (400) ,, ,,
Keweenawan sulfides	Late pre-Cambrian	570 ,, ,,

(Helium ages of pre-Cambrian magnetites (about 1,100 million) not included. The stratigraphical age of Blagodat is uncertain.)

It is obvious that the last word has not yet been said concerning the helium method. For the time being, the lead method will provide the more reliable age-estimates. But if the difficulties of the helium method could be conquered, it would afford certain advantages over the former, since it would make available for chronological studies many rocks which, on account of the presence of much common lead, are more or less unsuitable to be treated by the lead method.

Summary. Thus, the phenomenon of radioactivity of minerals has supplied a method for the measurement of geological time from the beginnings of the Pleistocene Ice Age back to very remote phases in the history of the earth. Earlier estimates based on the rate of deposition or denudation, on the salinity of the oceans, or on the

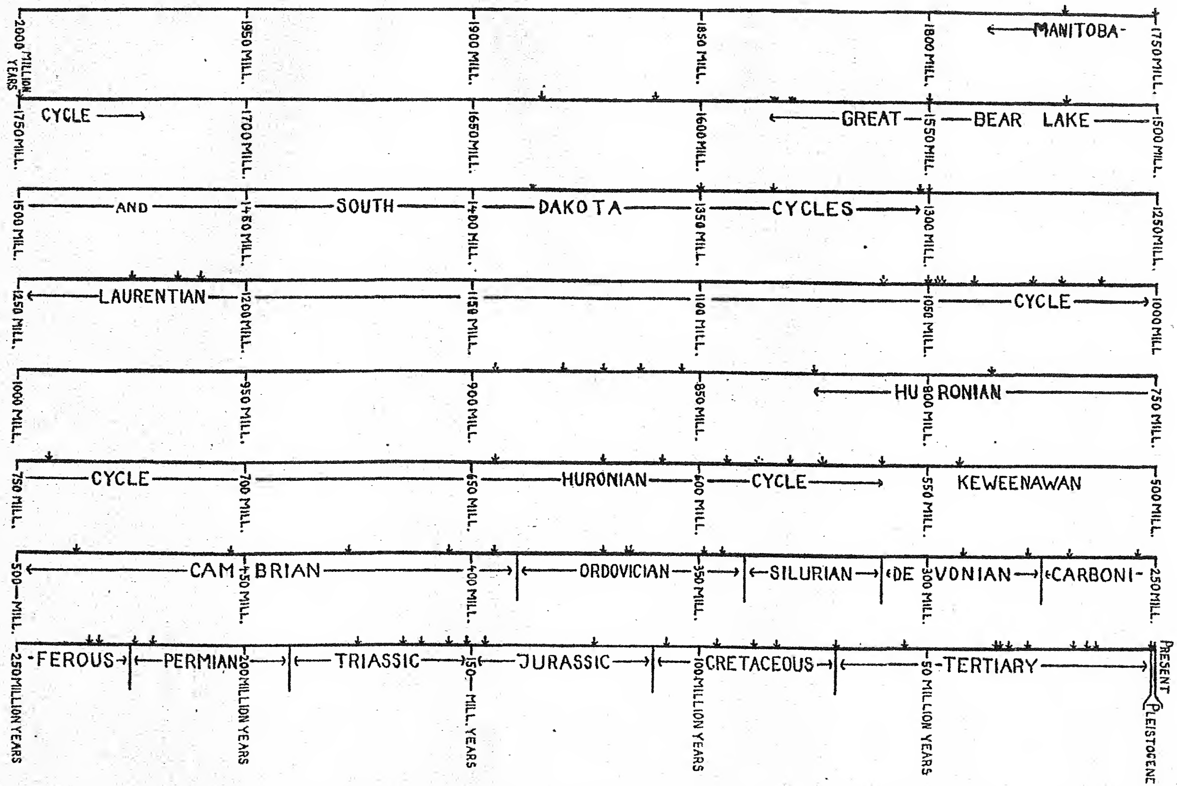


FIG. 89.—Time-scale for 2,000 million years of the earth's history. Important dates determined by the lead method are indicated by small arrows.

rate of evolution of life, have been superseded by accurate physico-chemical methods.

The most important method is based on the lead-ratio. The second, less reliable one, is the helium-method. Others, unimportant at present but promising for the future, are based on the pleochroic halos and on the radium/uranium ratio. Quite recently, attempts have been made to use the disintegration and accumulation of several other elements for the purpose of dating (for summary, see Lane, 1938). (See also note (9), p. 389.)

The results of the lead method are summarized in the diagram, fig. 89.

This table shows in a schematic manner the kind of knowledge supplied by the radioactivity methods. The dates obtained are confined to a small number of instants in the earth's history. The relative age in the stratigraphical scale being known, these dates tell us that a certain era, period or epoch was in progress at the time indicated by the specimen. Many more determinations will be required to narrow down the age-limits for the respective stratigraphical units.

An example may illustrate this. Dr. Urry found for the lowermost Jurassic an age of $146{\cdot}6 \pm 12{\cdot}8$ million years, and for the upper part of the Triassic $165{\cdot}8 \pm 2{\cdot}5$ million years (Lane, 1937). A basalt from the Cape Spencer Flow, Nova Scotia, of upper Triassic age, yielded 160 ± 8 million years or, if allowance is made for actino-uranium (Holmes, 1937, p. 178), 155 million years. It is therefore reasonable to draw the line between Triassic and Jurassic at about 150 million years before the present.

In this way, other important boundaries of the stratigraphical sequence are being, or will be, determined.

Although a great deal more will be known in a few years hence—workers on radioactivity are constantly increasing their activities—the dates already available enable one to draw some interesting conclusions regarding the age of the earth and of its inhabitants, and regarding the rate of evolution of the various forms of life. These fascinating problems will be considered in the following chapters.

CHAPTER XI

THE AGE OF THE UNIVERSE AND OF THE EARTH AND THE TIME RATE OF GEOLOGICAL PROCESSES

The time-scales described in the preceding chapters, though still fragmentary and uncertain in many details, enable us to obtain a somewhat clearer view of the rôle played by the time factor in the physical evolution of the earth. First, the results of the radio-

activity method have some bearing on our conceptions of the age of the Earth as a planet. Furthermore, the same method provides information about the duration of geological periods, and thirdly, the radioactivity, astronomical and varve methods permit us to determine the time-rates of certain geological processes, such as weathering and denudation, transgression of the sea, and crustal movements, including the rate of continental drift.

A. THE AGE OF THE EARTH

Minimum age derived from radioactivity estimates of terrestrial material. The 'age of the earth' is one of the outstanding problems to which the radioactivity method has supplied a partial answer. By making age determinations of the oldest known radioactive minerals and allowing for the still older rocks known to exist, a minimum age for the earth can be derived. The oldest radioactive minerals are about 1,750 million years old, and from this figure Holmes has estimated the minimum age of 1,900 to 2,000 million years for the earth. For at least the major portion of this time and probably the whole, however, conditions of temperature and climate must have resembled those of the present in all essential respects, as shown for instance by varved clays of pre-Cambrian age. If this figure were the real age of the earth, and not merely a minimum, a comparatively short space of time would have been available for the evolution of the earth from its birth as a member of the solar system to the period when organic life became possible.

The supposed 2,000 *million years limit for the universe.* What makes the figure of 2,000 million years (which, we must not forget, was obtained as a *minimum* estimate for the age of the earth) appear in a more serious light, is that the same figure has been postulated as the age of the whole universe by the 'short time-scale' astronomers. Readers who want to go more deeply into this matter will find all they require in Sir Arthur Eddington's Expanding Universe (1932).

The short cosmic time-scale is based on the recession of the galactic systems. The spectra of these distant nebulae appear to indicate that they are moving away from one another. If this movement is real, the universe must constantly increase its size. This is the basic idea in the theory of the expanding universe worked out by Eddington. In accepting the expansion one admits that the universe was smaller in the past and that it started from what is called a 'point-source'. Eddington has calculated on this basis that the age of the universe must be of the order of 10,000 million years, and probably near 2,000 million years. Holmes (1937) records the following arguments of Jeffreys in support of this result:

(1) The eccentricity of the orbit of Mercury suggests that the age of the solar system is nearer 1,000 than 10,000 million years.

(2) The tidal theory of the recession of the moon from the earth suggests that the age of the solar system is less than 4,000 million years.

Age of meteorites. Until a few years ago, the 2,000 million years 'age limit' appeared to find support also from age estimates of iron meteorites, the oldest then known being as old as 2,800 million years. The work on meteorites has been done chiefly by F. A. Paneth, and the method most commonly used is the helium-method. Paneth emphasises that, in this case, the results can be regarded as reasonably reliable, since meteoric iron has an extremely high helium-retentivity. Since 1937, Paneth has carried out a new series of determinations, with vastly improved methods (Arrol, Jacobi and Paneth, 1942). These have raised the 'age limit' very considerably, namely to 6,800 million years (Mount Ayliff and Morden meteorites).

On the assumption that these meteorites were always members of the solar system, the minimum age of the solar system, and with it of the earth, therefore appears to be at least 7,000 million years. This figure excludes the age of 2,000 million years for the earth as based on the theory of the expanding universe.

Suggested limits for the age of the universe and of the earth. Astronomical work has by no means been unanimously in support of the theory of the expanding universe, at any rate not of its chronological implications. Jeans (1942) has pointed out that, although as a whole the recession of the nebulae is demanded by theoretical considerations, the reddening of the spectral lines by which it is supposed to be measured, may well be due in large part to other causes, chief among them the effect of intervening matter which the light passes on its way from the nebula to the observer on the earth (Zwicky's theory). Jeans, therefore, concludes that 'if once it is accepted that the greater part of the velocities of recession may be treated as spurious, the argument in favour of short lives for the stars disappears, and we become free to assign to them the long lives of millions of millions of years which general evidence of astronomy seems to demand' (1942, p. 60).

Bart Bok and Watson (1940) have recently reviewed the astronomical aspects of the age of the earth for the Committee for the Measurement of Geologic Time and found that the astronomical evidence *at present available* renders it probable that the universe is less than 10,000 millions years old. If we take this figure seriously for the moment—it may have to be abandoned as research progresses—the age of the earth would appear to be greater than 7,000 million years, but less than 10,000 million years. The minimum age is a reliable value so far as it goes; the maximum limit, however, must be regarded as highly speculative. (See Note (7), p. 389.)

B. AGE AND DURATION OF GEOLOGICAL PERIODS

Returning to the known geological evolution of the earth, it is evident that the time-scales described in the preceding chapters help in estimating the age, as well as the duration, of geological periods. The radioactivity method has revealed some most instructive details. The pre-Cambrian history of the earth is at least three times as long as the entire history from the Cambrian onwards, which covers 500 million years. The Palaeozoic (Cambrian to Permian, compare fig. 83) comprises about 300 million years, or more than the Mesozoic and Cainozoic together (190–200 million years). This had always been suspected. The periods constituting the Palaeozoic average 50 million years each, the Silurian, Devonian and Permian being shorter, the Cambrian longer than the average. The Carboniferous coal of Europe and North America is about 240 million years old.

The Mesozoic is an era of comparatively short duration, about 120 million years. Of these, about 40 million are taken by the Cretaceous. The Tertiary with its 70 million years, on the other hand, has proved to be rather longer than supposed. The short estimates for the Tertiary had been based on the evolution of mollusca and plants, but the evolution of the placentalian mammals with their great variety of forms illustrates the duration of this period more adequately than the less rapidly evolving Tertiary mollusca and plants.

Again, within the Tertiary, the length of the Pliocene, about 13 million years on radioactive evidence, had been underestimated on palaeontological grounds, though it is possible that this figure has to be reduced when more reliably dated lower Pliocene rocks are investigated.

The duration of the Pleistocene, estimated at one million years by the radioactivity methods, and 600,000 to one million years by the astronomical method (depending on where the line between Pliocene and Pleistocene is drawn—Zeuner, 1944, p. 174), is well within the limits suggested by geological processes and the relative evolution of life. The Holocene, finally, may be taken as having lasted 10,000 to 20,000 years, according to how it is delimited from the Pleistocene. This delimitation is difficult (see p. 28) and varies in different regions of the earth.

C. TIME-RATES OF GEOLOGICAL PROCESSES

The figures thus obtained for the geological periods and epochs enable us to draw certain conclusions regarding the time-rates of geological processes. Curiously enough, this promising possibility has hardly ever been exploited, and a few examples must suffice here as illustrations.

Time-rate of weathering. The formation of soil-profiles in temperate Europe can be dated with a certain degree of accuracy. In abandoned gravel pits not more than about 100 years old I have found incipient soil formed under vegetation, to the depth of about 1 cm. This observation is consistent with the fact that brownearth and podsol profiles of Postglacial age, which have reached the mature stage, cannot be older than 10,000 to 15,000 years in many districts. It suggests that profiles of this kind require several thousand years to become mature. Furthermore, an observation in the blackearth district of Strehlen, south of Breslau (Silesia), where degradation of a previously-formed blackearth has begun, seems to indicate that two or three thousand years are not enough to develop a mature profile. This blackearth appears to date from the Boreal and may partly have been formed up to the Subboreal. If so, 3,000 years have not sufficed to superimpose upon the blackearth a brownearth profile. It is possible, however, that man kept this area open artificially. and thus produced a 'cultivation-steppe' under which the process of degradation would be much slower than under forest.

It is a fortunate coincidence that soil-profiles in temperate countries require several thousand years for their formation and not much more or much less. This period of time is too long for minor climatic fluctuations or exceptional weather conditions to find expression in the soil, but short enough to be completed during a single major climatic fluctuation of some ten thousand years' duration, as they characterize the European Pleistocene. For this reason, buried soil profiles are the most reliable evidence available for climatic fluctuations in the temperate zones.

One must not assume, however, that soil-profiles cannot be much older than, say, 10,000 or 15,000 years and still constitute the surface layer of the ground. Once a soil-profile has become mature, it may alter at a very slow rate or, under special conditions, become a 'dead' profile. This appears to have occurred in arid or semi-arid regions which have become dry after a humid phase. An outstanding example is provided by the lateritic crusts of tropical Africa and India which, it is claimed, date from the Tertiary and, therefore, would be well over a million years old.

Time-rate of erosion and denudation. The denudation of large surfaces, chiefly on slopes, is intimately connected with the linear erosion of the rivers and, either directly or indirectly, dependent on it. The time-rate of erosion varies enormously. In districts where it is intensified by tectonic movements or drops of sea-level, the rate of erosion is highest (provided climatic conditions are the same), whilst in districts in which no such changes have interfered and where little water is available the rate can closely approach zero.

Most important is the rate at which rivers cut down their thalwegs. Without entering into the somewhat complicated details of this

process it can be said that in the once glaciated or periglacial parts of Europe the interstadial, interglacial, or glacial phases (according to circumstances) have everywhere been long enough to enable rivers to cut down to a new level which, averaging very summarily, is some five to ten metres lower than the preceding. The duration of these phases may be taken as 20,000 to 40,000 years (on the evidence of the radiation curves), and the average of down-cutting of the thalweg would have been about 0·25 mm. per year, or one inch in a hundred years. This amount, or some other near it, accounts for the erosional processes which produced the Pleistocene river terraces in temperate Europe.

Much higher values are obtained (*a*) near the mouths of rivers in gorges cut during phases of low sea-level, (*b*) where the river crosses an active fault, and (*c*) where displacement of the river's course compels it to cut through an obstacle. If the rock is soft or even loose, the erosion can assume catastrophic proportions, resulting in many metres of cutting within a few days, as for instance when Lake Ragunda was suddenly drained in 1796 (see p. 26). It is of little use, therefore, to calculate figures for a maximum rate of cutting.

The time-rate of the denudation of slopes, and of the development of denudational cycles which ultimately may lead to the formation of peneplains, is difficult to estimate, since the recession of the slopes usually destroys the very elements on which dating can be based, such as terraces, moraines, or other superficial deposits. It is safe to say, however, that peneplanation or anything remotely approaching it, requires a period of time far exceeding the duration of the Pleistocene.[1] Where an area has developed beyond the mature stage of the physiographical cycle, evidence can often be found that this condition had been reached previous to the beginning of the Pleistocene and that the effects of the Pleistocene are confined to repeated rejuvenation. From this it is clear that the reaching by an area of the senile stage of geomorphology requires many millions of years [2] and that it is extremely unlikely ever to have been achieved within the one million years assigned to the Pleistocene.

Time-rate of ice-recession. Another geological process the rate of which has been determined by geochronological work is the recession of the ice-margin during the late glacial stages in north Europe and North America. Since the ice-margin began to recede from a halt, the amount of annual recession must have risen from zero to at least the greatest value known. High values were obtained in Sweden in connexion with studies on annual moraines and varves, as explained

[1] This does not apply to areas composed of soft and loose rocks (sands, gravels, moraines, &c.) which may reach the senile stage very rapidly.

[2] Baulig (1935, p. 30) estimated the time required for the peneplanation at at least 5 million years. It depends, of course, enormously on the initial height of the region being denuded.

on p. 23. De Geer (1940, p. 154) found that in some cases the ice-margin retreated 400 metres annually but, since this was during a late stage of the Last Glaciation, the annual rate of retreat must have been much less than this for the major part of the recession.

Time-rate of marine transgression. Some valuable figures can be obtained for the rate of rise of the sea-level and the corresponding recession of the coast-line, in other words for the rate of marine transgression. For the Postglacial transgression, Godwin's and other authors' work suggests an annual rise of 1 cm. during the major parts of the Boreal and Atlantic phases (see p. 93). This figure illustrates the eustatic rise of the sea-level after the Last Glaciation, which was rapid. Similar figures are likely to apply to the rises which occurred during the early parts of the interglacial phases.

The recession of the coast-line which corresponds to such a rise in sea-level depends on the configuration of the submerged land. It varies from almost zero on perpendicular, resistant cliffs to as much as 350 km. in the middle portion of the North Sea during the Boreal and early Atlantic. This advance, over almost level ground, proceeded at the rate of at least 100 m. per year; and there appear to have been few cliffs obstructing it.

The formation of a platform of abrasion, though it begins with the transgression, continues during the subsequent phase of high sea-level (neglecting in this context slight oscillations, see p. 93), and much of the marine abrasion in the soft rocks of the North Sea area is definitely the result of wave-action during the 7,500 years of high sea-level which followed the Boreal transgression. The value of 18 metres (60 feet) for a single year, reported by Whitaker (1907) from Covehithe, Suffolk, is exceptional. At Cape Arkona, on the Baltic island of Rügen, the chalk cliff, which is 44 m. high, has been cut back by 300–400 metres in a hundred years (Neumayr and Suess, 1920). The cliffs of Heligoland, composed of Triassic sandstone (pl. XXI, fig. B), lost about 1 metre annually, according to my recollection, before protective measures were carried out. Annual rates of coastal destruction of one to a few feet can be observed in many places along the soft cliffs bordering the North Sea.

On rocky coasts bordering a less shallow sea and composed of resistant rocks, however, the result of 7,500 years of continuous wave action is very small. In extreme cases nothing more than a notch may have been cut, or a bench a few metres wide. Since the time, during which these benches were cut, is known fairly accurately, it will be possible in many places to calculate the amount of material removed, accounting for the width of the bench produced and for the height of the cliff.

The earlier Pleistocene transgressions have all produced effects which quantitatively are comparable with that of the Postglacial. All the Pleistocene transgressions together have nowhere been able

to alter substantially the configuration of coastlines composed of resistant cliffs. The available time was obviously not sufficient to produce greater effects.

From this one cannot but draw the conclusion that the great transgressions of pre-Pleistocene times, such as that of the upper Cretaceous for instance, belong to a different category. Platforms of abrasion were then cut which cover sometimes large portions of continents, and they were cut into any kind of rock, resistant or soft. These great transgressions, therefore, cannot have been the product of fluctuations of sea-level of some 10,000 years (as are those of the Pleistocene), but of periods lasting many times longer. There is also evidence that such transgressions were more gradual in their rising and that the rise of sea-level was more persistent than those of the Pleistocene sea. It is probable, therefore, that transgressions of this type, which can be used for the distinction of major stratigraphical divisions, lasted through hundreds of thousands, or even millions of years.

Time-rate of climatic fluctuations. Since, with the exception of the radioactivity method, geochronological work depends largely on the study of climatic cycles, it is not surprising that our knowledge of the duration of climatic fluctuations has much increased in connexion with this work. The short cycles, of which the sunspot cycle of 11·4 years is the most outstanding, may influence the weather periodically but are in any case too short to be considered as climatic fluctuations.

The major planetary perturbations, with oscillations of from 21,000 to 92,000 years, however, have produced climatic fluctuations of a length sufficient to leave geological evidence (p. 142). As shown in Chapter V, this applies in particular to the Pleistocene. It is possible that similar fluctuations in the Permo-Carboniferous Ice-Age of the southern hemisphere, for which some evidence has come forward, were of the same type. Furthermore, Gilbert has tried to recognize the precession cycle in Cretaceous sediments (p. 311). It may be expected that the cycles of the perturbations will be discovered in other geological epochs also.

Rhythms in the history of the Earth. The fact that the cycles of the perturbations have left distinct traces in the Pleistocene deposits but not in the Tertiary suggests that there are superimposed cycles, or non-cyclic changes of a considerably longer duration, i.e. of millions of years.

It has been suggested that the appearance of glaciations at the end of the Tertiary is connected with the heightening of the crustal relief as the result both of upheaval of portions of the crust and of a dropping of the sea-level (Zeuner, 1944, p. 164).

In recent years, a number of workers have come to the conclusion that the relief of the earth's surface was intensified at intervals

during periods of increased orogenic (mountain-forming) activity, and that these episodes are somehow coupled with two other ‘ cycles ’, that of magmatic intrusions and that of the transgression and regression of the sea. There is no need here to discuss these theories, especially since excellent summaries have been published by Umbgrove (1939*a*, *b*), from which I am quoting the following words (1939*b*, pp. 449–50; see also fig. 90):

(1) Worldwide transgressions and regressions are probably caused by simultaneous but opposite movements of both continents and level of the sea.

(2) The periods of regression coincide with orogenic epochs, which are relatively short in comparison with the much longer intervening periods, which are at the same time periods of transgression.

(3) The movements of the level of the sea and the continents as well as the orogenic epochs are caused by processes in the substratum, which elapsed periodically, as it were with a pulsating rhythm.

These striking events can be explained if an alternating expansion and contraction of the substratum takes place.

The application of the absolute time-scale to these rhythmic processes is of great interest. A. Holmes has paid special attention to this matter, which is bound in the course of time to bring out the length and character of the rhythms involved. Holmes (1937, pp. 185–214) extended the dating of the cycles to the pre-Cambrian periods (fig. 91) and specified the intervals between the culminations of the major orogenic cycles approximately as follows (compare figs. 82 and 89):

North America	Interval	Million Years B.P.	Interval	Europe
Pacific (Cordilleran)				Alpine
	190	190	190	
Appalachian				Hercynian
	90	280–310	120	
Acadian				Caledonian
	220	400	190	
Keweenawan				Jotnian (May be too long)
	240	640–725	325	
Algoman				Gothokarelian (May be too short)
	285	925–915	190	
Laurentian				Svecofennian
	275		270(?)	
Great Bear Lake Athabasca Black Hills, Upper	535	1460–1455	540	?Norwegosamian
	280		270(?)	
Black Hills, Lower				Marealbian
	170	1630		
Manitoba				

This table shows that the periods of the last three cycles are reasonably consistent with each other, lasting for 120 to 190 million

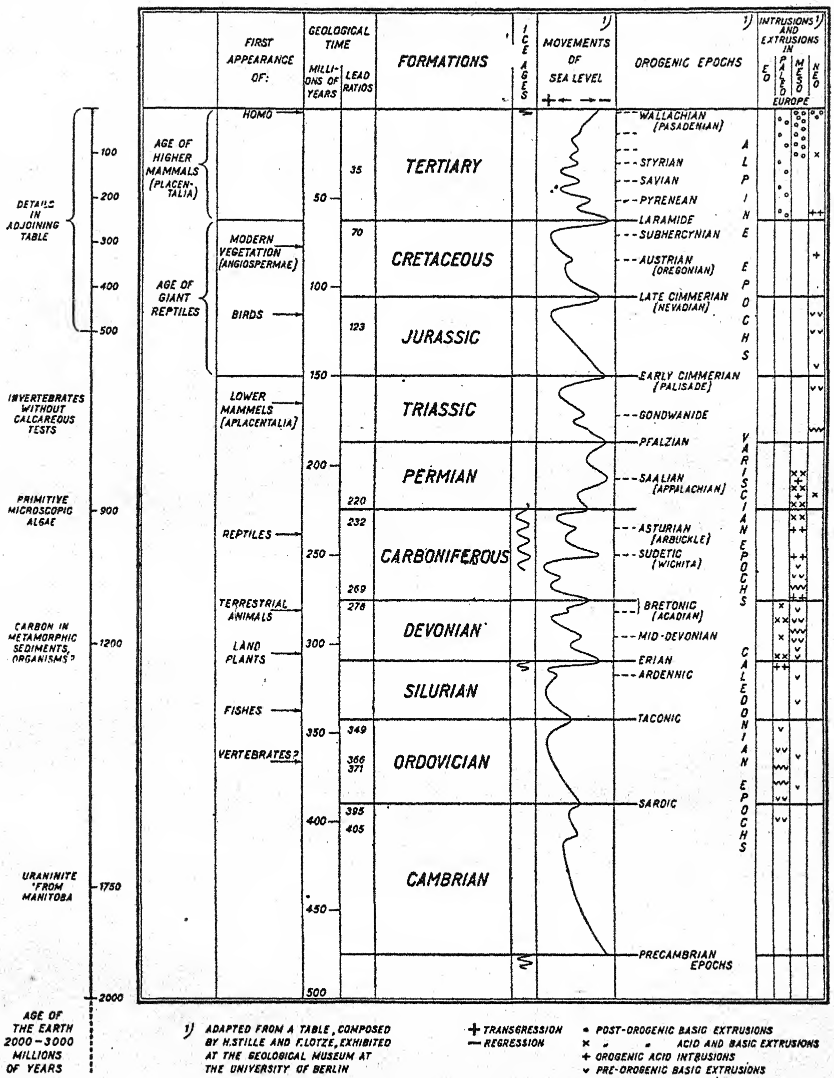


FIG. 90.—Umbgrove's table of 'Rhythms in the History of the Earth'. Reproduced from Geol. Magazine, 1939, with permission.

years. Since the episode leading up to the climax of the Gotho-karelian cycle of the Pre-Cambrian also may have lasted 190 million years, some regularity of the rhythm is suggested. On the other hand, the figures from North America in particular indicate that the intervals between the culminations of the orogenic epochs may have become shorter in the course of the earth's history. This is Holmes's latest view.

The theory of rhythms in the development of the earth's crust is being elaborated by several other workers like Bucher (1933, 1939) and Grabau (1940). A summary table which combines Stille's

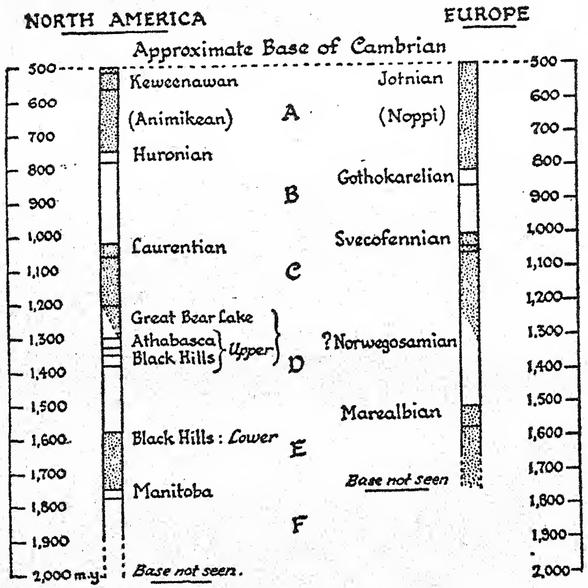


FIG. 91.—Chronological Table of the pre-Cambrian periods of North America and Europe.—From Holmes (1937, p. 209), with permission.

orogenic studies with Holmes's work is reproduced here (fig. 90) from Umbgrove (1939*a*). There is no doubt that in this field the gradual development of a reliable time-scale is providing an invaluable key to further discovery (Holmes, 1937).

Time-rate of tectonic movements. The rates at which tectonic movements operate can either be measured directly or computed from geochronological evidence. We are here chiefly concerned with the latter method. In reviewing some examples it is advisable to distinguish vertical and horizontal movements.

Time-rate of faulting and local disturbances. Vertical movements have been calculated for the great fault which separates the central Sudeten mountains from the lowlands of Silesia (Zeuner, 1928).

This fault cuts across the terraces of the rivers, and the terraces have been lifted up with the mountain block. Since their approximate age within the Pleistocene is known; the annual rate of upheaval can be found with the aid of the astronomical time-scale. The rate proves to be rather low, 0·2 to 0·5 mm. per year. Comparing this value with the average value for the down-cutting of the rivers (0·25 mm., see p. 339), one understands why no rapids or falls have developed over this fault, which nevertheless has created a spectacular mountain wall.

Observed modern values from tectonically active areas suggest that the rate of vertical movement is sometimes considerably higher. The Serapis temple at Pozzuoli near Naples, which stood on dry land when built by the Romans, had since become submerged to a depth of at least 20 feet and has risen again to about sea-level (for summary, see Lake and Rastall, 1913). Assuming that the phases of submergence and subsequent rising were about equal in duration, the annual average of movement is about 6 to 7 mm. As they probably were not equal, one of the movements must have taken place at a rate faster than this.

Many still higher values have been observed for local movements, but they come from earthquake areas and, therefore, are liable to being exceptionally high.

Time-rate of isostatic movements. Another type of vertical movement is the isostatic response of parts of the crust to the weight or removal of ice and more generally, to the weight of deposits or the removal of rocks. The upward movement of Scandinavia since the Last Glaciation has been dated by Swedish and Finnish investigators who studied the inclination of coastal terraces which must have been horizontal originally and which can be dated by means of the varve chronology (see p. 47, figs. 14, 15). As an example, two figures deduced from one of Sauramo's papers (Sauramo, 1919) may be quoted. The shore-line of the Ancylus Lake in southern Sweden and Finland has risen in places by at least 110 metres since 7400 B.C. The average annual rise, therefore, was 1·2 cm. per year. The Litorina Beach in middle and west Finland has risen by 90 metres since 4000 B.C., the annual rise being 1·5 cm. per year. These two figures agree very well. Harbours in Sweden which were still navigable in the Middle Ages have since fallen out of use as they have become too shallow.

Time-rate of folding and rise of mountain ranges. A complicated combination of vertical and horizontal movements resulted in the building-up of mountain ranges of the alpine type. These processes were very intense during certain geological phases, so that any average values derived for the time from the formation of marine rocks now raised to great heights up to the present day cannot be more than minimum values for the actual rate of upheaval. The

following rates have been calculated to provide some idea of the intensity of such movements. They rely on evidence of certain marine sediments found at great heights and on the ages of these sediments as suggested by the radioactivity time-scale.

	Annual rate per annum
Alps, Mt. Säntis, Switzerland. Upper Cretaceous at 2,500 metres	0·03 mm.
Himalayas, Mt. Kinchinjunga. Upper Cretaceous at 8,400 metres, teste Dyhrenfurth	0·11 mm.
New Guinea, Carstenz Range. Lower Neogene at over 4,800 metres, teste van Bemmelen, 1939	0·2 mm.
Timor, Plio-Pleistocene coral reefs raised to 1,300 metres, teste Brouwer, 1925	0·2–1·3 mm.

Time-rate of relative displacement of poles and climatic zones. Two types of large-scale horizontal movements have to be distinguished, one resulting from the relative displacement of the rotational poles, and another resulting from a drifting of single crustal blocks. In practice, both took place simultaneously and are difficult to distinguish, except in certain cases.

The shifting of the poles implies a shifting of the equator. It must be understood clearly that this is not an actual displacement of the rotational axis, but merely a movement of the crust of the earth over the interior core. It is therefore purely relative, but has inevitably a great effect on the position of the climatic zones, since parts which once lay far distant from the pole, may be shifted into higher latitudes, and vice versa.

Since it is possible to reconstruct to some extent the tropical and subtropical zones for the past geological phases, evidence suggestive of displacement of the poles has been obtained. The rate of displacement calculated by Köppen and Wegener (1924) for the late Tertiary and Pleistocene, however, is probably too large. Milankovitch (1934) has more recently calculated the past movements of the poles on purely geophysical grounds but has been unable to apply a time-scale to them.

The great effect of the displacement of the poles is the corresponding shift of the climatic zones. It will be necessary to establish the position of the climatic zones in successive geological phases before the movements of the poles can be dated in detail. Kreichgauer (1902), Wegener (1937), Köppen (in Köppen and Wegener, 1924), and others, have begun work on these lines, using the available evidence for the subtropical dry belts and the tropical rain-forest zone, but much more thorough research is needed to provide a reliable basis. At the present moment, only the movements of the equator during the Tertiary appear to be somewhat securely established. They seem to indicate that Malaya was in the equatorial zone throughout the Tertiary and that, thence, the equator ran up to the northern Mediterranean in the Eocene, and through Gambia,

West Africa, in the Miocene. Assuming that continental drift did not displace Africa relative to Europe, the equator would have moved southwards, say, from Spain via west Africa to its present position through 4,500 km. in about 50 million years, or 9 cm. per annum.[1] This figure is bound to be very rough, but it at least indicates the rate of a movement of the climatic zones which must have been of overwhelming importance in the history of the distribution of the floras and faunas.

Time-rate of continental drift. The 'continental drift' is a large-scale horizontal movement of continents or other large blocks of the earth's crust. It was independently postulated by Taylor and by Wegener about 30 years ago. It is still a controversial subject, though an increasing number of geologists are prepared to admit the reality of movements of this kind. Particularly with respect to the drifting of South America away from South Africa evidence has been brought forward which it is difficult to reject. Another region where most geologists admit drifting is that between southern Asia and Australia. The evidence for all parts of the world will be found in a book by du Toit (1937). The most widely known treatise on the theory is Wegener's original book (1937 and earlier editions). Holmes (1929) has published a valuable review of the different aspects of the theory and an up-to-date treatment may be found in his *Principles of Physical Geology* (1944, Chapter XXI). Wittmann (1934) has surveyed the biological evidence adduced in favour of the theory of continental drift, and the present author has studied a case of distribution of an insect genus in the Australasian archipelago which would be difficult to explain without accepting a north-westward movement of New Guinea and Australia (Zeuner, 1943).

The chief problem of the theory of continental drift is not the principle involved (horizontal movements of some kind or other being too obvious to be denied as such) but rather their intensity and rate. The figures which Wegener gives (1937) for the average rate of horizontal movement are based (*a*) on the geological phase during which, according to him, the separation of two blocks began, and (*b*) on estimates for the duration of geological periods which are considerably too small, judged by the recent results of the radioactivity method. Point (*a*) cannot be discussed here, being beyond the subject-matter of this book. Point (*b*) tends to increase the average rate computed. In the following table, some of Wegener's

[1] Compare with this the changes of geographical latitude observed at many stations in recent years (Lambert, 1925). Most of them (chiefly European) point to a movement towards the equator. Some specimen values (per annum, based on short periods of observation, ranging from 15 to 70 years) are: Paris, 1·00 metres; Rome I, 0·75 metres; Königsberg in Prussia, 0·30 metres; Rome II, 0·15 metres. If real, these displacements may be caused either by polar shift, or by continental drift, or by more local movements in the crust; they cannot be regarded as evidence for the displacement of the poles.

rates previous to the Pleistocene[1] have been re-calculated, using the latest datings obtained by the radioactivity method, as given by Holmes. This table must not be regarded as more than what it is:—a list of average rates of continental drift which would apply if Wegener's views regarding the original position of the blocks and their respective times of separation are correct.

	Distance km.	Time of separation	Years of separation	Annual rate of drift
Cape Farewell (Greenland)—Scotland	1,780	Pleistocene	50,000–100,000	36 to 18 metres
New Foundland—Ireland	2,410	Early Pliocene	12–16 million	0·2–0·15 metres
Buenos Aires—Cape Town	6,220	Cretaceous	90 million	0·07 metres
Peninsular India—South Africa	5,550	Early Tertiary	70 million	0·09 metres
Tasmania—Wilkes Land (Antarctica)	2,890	Early Oligocene	45 million	0·07 metres

One notices that the annual rate of drift previous to the Pleistocene would have been a few centimetres per year, an amount which is in good keeping with the values obtained for other kinds of crustal movements. Wegener's figures for the Pleistocene, however, are exorbitantly high (ranging from 9 to 36 metres annually). This is partly due to his assumption that the separation of North America from Europe occurred in the late Pleistocene. Even if one removes the time of separation to the end of the Tertiary (one million years ago), one would still obtain annual rates varying between 1·8 and 0·9 metres, values which are ten to twenty times higher than the moderate rates obtained for the earlier drifts. This discrepancy either calls for a special explanation, or else it reveals that Wegener was mistaken in assuming so late a date for the separation.

The northward movement of Peninsular India, in connexion with which the Himalayas were built up, affords a means of checking Wegener's values. He supposes that India originally lay to the east of South Africa and that it began to move northwards at the beginning of the Tertiary. Argand has since estimated the compression suffered by the Himalayan region in the course of the folding process and arrived at 3,000 km. The folding movements are likely to have begun rather earlier than the early Tertiary, since there is evidence from the Mesozoic. Assuming that they began towards the end of the Triassic (150 million years ago), the average rate of northward

[1] Only one of Wegener's values for the Pleistocene is included in my table.

movement of the Peninsula can be calculated as 0·02 metres.[1] This figure falls in the same category as the figures for the earlier drifts in our table, and agrees also with the amounts for other large-scale crustal movements.

In recent years attempts have been made to determine the rate of continental drift directly by measuring carefully and at intervals the geographical longitudes of stations in Europe, and in Greenland and North America. The results have been summarized by Wegener (1937, pp. 24–32, p. 206), who derives from them much support for his claim that the Pleistocene and Recent movements are very fast.

According to repeated measurements, some carried out with refined methods, the annual rate of westward drift of Greenland would be as much as from 9 to 36 metres, values which, one has to admit, agree with those derived by Wegener from geological evidence. The corresponding rate for North America, however, is considerably smaller. Up to 1927 the westward drift of North America was not considered as reliably measurable, but longitude determinations carried out in 1927 (Littell and Hammond, 1928) suggest an annual rate of 0·32 metres. This is only one-hundredth of the larger figures obtained for Greenland. It cannot be doubted that such measurements will eventually settle the problem of continental drift, the amounts involved being large enough to be detected by modern methods. It will, however, require also much geological research to show that the figures obtained are those for the drift of continental blocks, and not due to tectonic movements of smaller portions of the crust.

Thus, the figures at present available suggest that the rate of horizontal movements is about 10 to 100 times greater than that of vertical movements.

Conclusion. The preceding review of applications of geochronological time-scales to geological events and processes is anything but complete. It merely intends to indicate the lines along which it will be possible gradually to transform our deep-rooted conceptions of relative time in geology into terms of absolute time. A great field is open here for future research.

[1] My friend, Mr. Day Kimball, has pointed out to me that on the whole the strata in the Himalayas show no erosion surfaces till the Eocene. The rate, therefore, may have been as high as 0·06 metres per year.

CHAPTER XII

BIOLOGICAL EVOLUTION AND TIME

A. THE AGE OF SOME GROUPS OF ANIMALS

The significance of geochronology for studies in the evolution of life can hardly be overestimated. Until the first time-scales appeared, the palaeontologist was much in the same position in which a historian would find himself who knew the correct succession of events in human history, but not the dates. Dates in years, even if they are only approximate, enable palaeontologists as well as historians to see events and developments in their true chronological proportions and to deduce from them some of the hidden rules of life.

As geochronology is still in its infancy and since the time-scales are as yet incomplete, it is not surprising that little use has been

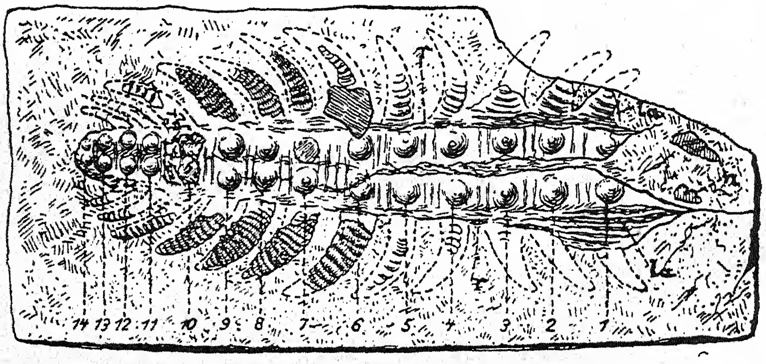


FIG. 92.—*Xenusion auerswaldae* Pompeckj. Algonkian Dala Sandstone from central Sweden, found in a glacial erratic at Heiligengrabe, Mark Brandenburg. A representative of a group intermediate between annelid worms and Arthropoda. —From Pompeckj (1927).

made of them in research bearing on evolution. It is intended, therefore, to show in the following paragraphs that promising possibilities are contained in a combination of geochronological and palaeontological investigations. Since this matter goes somewhat beyond the main subject of the present book, it can only be treated in a very sketchy manner. I hope, however, to give elsewhere a more elaborate account of the rôle which the time-factor plays in biological evolution.

Absolute age of some groups of animals. The most obvious application of time-scales to palaeontology is in determining the approximate minimum time during which certain groups are known

to have existed on earth. A few instances are compiled in the following table :

Group	Stratigraphical Age	First appearance, years ago	Minimum period of existence
(1) *Xenusion auerswaldae* Pompeckj (1927) *	Dala Sandstone, Upper Pre-Cambrian (?)	500–800million	—
(2) Trilobites	Early Cambrian to Permian	500 million	310 million
(3) Scorpions	Silurian to Recent	390 million	390 million
(4) Wingless Insects; *Rhyniella praecursor* Hirst and Maulik, see Scourfield, 1940 †	Middle Devonian	300 million	300 million
(5) Winged Insects	Upper Carboniferous	250 million	250 million
(6) Protorthoptera (ancestors of following three groups)	Lower upper Carboniferous to Permian	250 million	60 million
(7) Cockroaches	Middle upper Carboniferous to Recent	240 million	240 million
(8) Saltatoria (grasshoppers, &c.	Middle upper Carboniferous to Recent	240 million	240 million
(9) Beetles	Upper Permian to Recent	200 million	200 million
(10) Caddisflies (and moths ?)	Rhaetic (upper Triassic) to Recent	160 million	160 million
(11) Lingulidae, Brachiopoda	Lower Cambrian to Recent	500 million	500 million
(12) Genus *Lingula*	Ordovician to Recent	390 million	390 million
(13) Vermes	Middle Cambrian to Recent	440 million	440 million
(14) Jawless fishes	Ordovician to Recent	360 million	360 million
(15) Placoderm fishes ‡	Devonian and lower Carboniferous	310 million	40 million
(16) Shark-like fishes	Upper Silurian to Recent	320 million	320 million
(17) Bony fishes	Devonian to Recent	300 million	300 million
(18) Amphibia	Upper Devonian to Recent	285 million	285 million
(19) Reptilia	Lower Carboniferous to Recent	270 million	270 million
(20) Birds	Upper Jurassic to Recent	120 million	120 million
(21) Mammals	Upper Triassic to Recent	160 million	160 million
(22) Multituberculate mammals	Upper Triassic to Eocene	160 million	100 million
(23) Pantotheria (pre-marsupial mammals)	Upper Jurassic	130 million	20 million
(24) Marsupials	Upper Cretaceous to Recent	80 million	80 million
(25) Placentalian mammals	Upper Cretaceous to Recent	80 million	80 million
(26) Lemurs	Eocene to Recent	60 million	60 million
(27) Man-like apes	Lower Oligocene to Recent	50 million	50 million
(28) Man	Late Pliocene (?), Pleistocene to Recent	1 million §	1 million

* Fig. 92. † Earliest insects; order Collembola ‡ See Westoll (1943).
§ With allowance for evolution up to the stage of Heidelberg and Pekin Man.

This table requires no direct comment, but it suggests a number of possibly significant features in the relation of evolution to time which need to be discussed in some detail.

B. EXPLOSIVE EVOLUTION

In the first place, the table illustrates what in palaeontology is called *explosive evolution*. When a major group appears, one often observes that its main subdivisions also appear within a comparatively short space of time. This episode is followed by a longer stretch of time when evolution proceeds at a quieter pace.

More or less simultaneous appearance of major systematic units.—Classes and orders.—Insects. The table contains two instances of taxonomic orders appearing all within a comparatively short space of time. The first is that of the winged insects (rows 5 to 10 in the table) which could have been amplified greatly by including a larger number of orders. A summary table published by Martynov (1938) which distinguishes over 100 orders of insects provides the basis for a numerical analysis of the evolution of this class. Neglecting the four orders of the wingless insects (Apterygota) which constitute an older stock (see table, row 4) about 100 orders of winged insects (Pterygota) are left.[1] Of these, the following orders are present, or appear for the first time, in the following periods:

Number of orders	Present in the	New orders appearing
0	Devonian	0
0 (2)	Lower Carboniferous	0 (2) *
18	Upper Carboniferous	18 (16) *
37	Permian	30
31	Mesozoic	22
38	Tertiary	13
48	At the present day (of these 7 without fossil record).	

* No winged insects are known earlier than the base of the upper Carboniferous but it is to be presumed that the two orders then appearing date back to the lower Carboniferous.

If one plots the number of new orders which appeared during the Carboniferous, Permian, &c., on the radioactivity time-scale (fig. 93), it becomes clear that an exceptionally large number of new orders evolved during the 60 million years of the upper Carboniferous and Permian, that this episode was apparently preceded by an insignificant initial phase, and that the rate of appearance of new orders has since slowed down. The figure given for the Tertiary is too high, and due to lack of fossil evidence from the Cretaceous.

[1] One may disagree with parts of Martynov's classification. He has a tendency to raise suborders and families to ordinal rank. But for the present purpose this matters little.

It is almost certain that the majority of Tertiary orders date back at least to the Cretaceous.

Vertebrates. Another instance of quasi-simultaneous evolution of classes and orders is provided by the primitive vertebrates (fig. 94). Three classes of fishes, and the Amphibia, appear in the Silurian and Devonian, apparently evolving from the jawless vertebrates, either directly or indirectly. The latter (Agnatha) also appear in at least four different lines in the Silurian and Devonian, whilst only one is so far known from the Ordivician. This splitting of the primitive vertebrates seems to have taken place within about 60 million years and there is reason to believe that the transition from the crossopterygian fishes to true Amphibia was performed in a

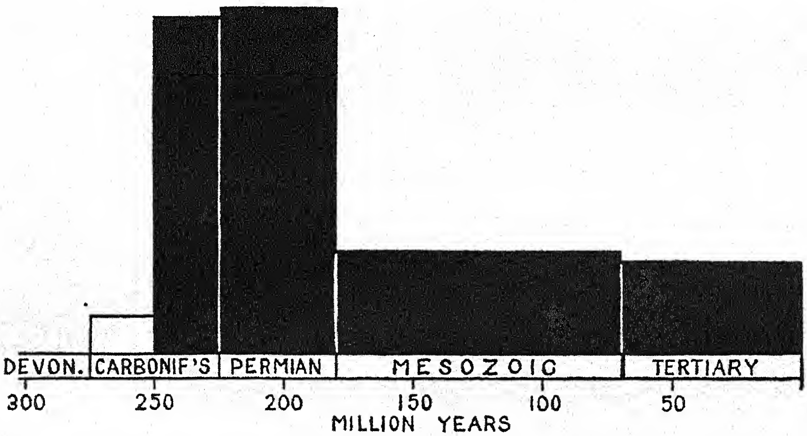


FIG. 93.—Insect orders. Numbers of *newly appearing* orders plotted against time, surface areas proportional to numbers. Two orders presumed present in the Lower Carboniferous.—Based on material provided by Martynov (1938).

period of the order of 15 million years (within the upper Devonian; Westoll, 1943, p. 95). In the remaining 275 million years up to the present, only three new classes have appeared. Of these, the reptiles have been found in the upper Carboniferous, so that one may regard them as the last sprout of the middle Palaeozoic episode of evolution. The remaining two are the birds and mammals which, incidentally, arose from the reptiles when these had their episode of explosive evolution during the Mesozoic.

This sudden appearance of the higher systematic groups, like classes and orders, within a relatively short period of the earth's history, i.e. within considerably less than 100 million years, can hardly be due to the chances of preservation. It may be admitted that the earliest vertebrates had no hard parts which would readily become fossilized. But the absence of winged insects in the lower compared with their abundance in the upper Carboniferous is a telling fact,

since both lower and upper Carboniferous contain facies suitable for insect-preservation. In this case at least, the sudden abundance is most probably due to an outburst of evolution. The same applies to many other instances derived from later deposits.

It is suggested, therefore, that *there have occurred in the evolution*

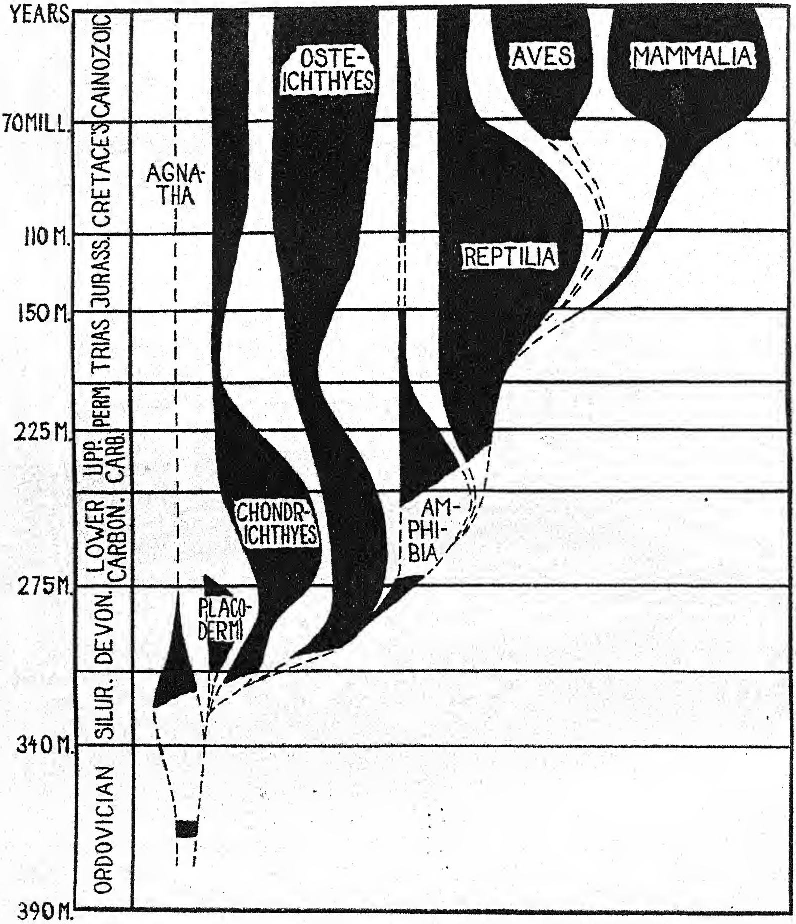


FIG. 94.—Phylogenetic tree of the Vertebrata, plotted on the time-scale.—After Romer (1933), modified.

of certain phyla short episodes during which the majority of classes and orders were born. These episodes appear to have lasted for something like 50 to 100 million years.

Families and genera. The question now arises whether the evolution of families, genera and species is a similarly explosive process, or more continuous. For families, the instance of the

Artiodactyles may be mentioned (compare Romer, 1933, fig. 302). These appear in the lower Eocene with the primitive Homacodontidae, which presumably are of pre-Eocene origin. By the end of the Eocene, 14 new families have appeared, and the Homacodontidae die out. During the Oligocene, differentiation of new families was confined to the Tragulid stock since, in the Miocene, the deer and cattle families emerge from it, four in all. In the Pliocene, finally, one more family, the Hippopotamidae, is added to the Artiodactyles. These figures suggest that the explosive evolution observed in some higher taxonomic categories applies to families also, but in our particular case we have evidence that the explosive episode did not last longer than some 15 million years.

Genera. With respect to genera, the Terebratulidae (Brachiopoda) may be quoted. Schuchert and LeVene (1922) list

4	genera	for	the	Triassic
24	,,	,,	,,	Jurassic
10	,,	,,	,,	Cretaceous
6	,,	,,	,,	Cainozoic

The Terebratulidae thus appear to have passed through an episode of intense genus-evolution during the Jurassic, lasting for some 40 million years.

Species. Finally, we come to the rate of appearance of new species within a genus. Good examples for this process are provided by the Mollusca (material derived from Wenz, 1923–30). In the genus *Poiretia* Fisch., for instance, the following number of *new* species have appeared:

Poiretia	during	the	Paleocene,	3	new	species
	,,	,,	Eocene,	13	,,	,,
	,,	,,	Oligocene,	14	,,	,,
	,,	,,	Miocene,	19	,,	,,
	,,	,,	Pliocene,	5	,,	,,

This genus experienced an episode of abundant species-evolution from the Eocene to the Miocene, or roughly for 40 to 50 million years.

In other genera, this episode was shorter, as for instance in *Cepaea* Held., where it was confined to the Miocene, a period which is unlikely to have lasted for less than 15 million years.

Other genera again have been increasing the pace of production of new species in the course of the Tertiary and have not yet passed the climax of their phase of abundant species-evolution. *Theodoxus* Montfort, *Melanopsis* Férussac, *Limnaea* Lam., and *Gyraulus* Ag. are in this category; the figures for the last-named may serve as an example:

Gyraulus	during	the	Paleocene,	1	new	species
	,,	,,	Eocene,	2	,,	,,
	,,	,,	Oligocene,	18	,,	,,
	,,	,,	Miocene,	33	,,	,,
	,,	,,	Pliocene,	79	,,	,,

One may say that the episode of abundant species formation began in the Oligocene. It has lasted through the major portion of the Tertiary, and therefore for some 40 million years.[1]

Phases of abundant production of new taxonomic units. Summary. The conclusion to be drawn from this sketchy survey is that there are episodes of abundant production of new types which last for a few tens of millions of years. These episodes are not appreciably longer for the higher systematic categories than for the lower. This raises two problems. First, why are these episodes not dependent on the systematic category? It seems to me that the answer rests in the lowest common denominator, i.e. the species. We shall have to return to this point again later on (p. 363).

The second question is whether these episodes of abundant production of new types occur in every stock and every lineage without exception. This is probably not the case, as there are many groups which linger on for a great length of time without ever increasing appreciably their rate of production of new types. An instance of this kind is shown in the phylogenesis of the true fishes (fig. 95). The Coelacanthini continue from the Devonian to the present day; their rise was exceedingly slow (about 100 million years, from middle Devonian to end of Palaeozoic), their best times, if one call it that, were during the Mesozoic (130 million years), and one species has survived to the present day. The Dipnoi, or lung-fishes (fig. 95) seem to have experienced several slight outbursts of evolutionary activity, but they, too, did not reach the level of 'explosive evolution', so clearly exhibited by the four remaining orders of fishes in this table.

Time-frequency curves. So far, the discussion has been restricted to the rate of production of *new* types, and the question of survival has been neglected. If one wants to obtain a picture of the 'vigour' of a group, expressed by the number of lower taxonomic units existing at any particular time, the number of units existing at that time must be considered, irrespective of whether they were newly-evolved or survivors. The number of lower units (e.g., species in a genus, or genera in a family) plotted against time, produces a most instructive type of curve which might prove to be a help in phylogenetic research. It is here called *time-frequency curve*, and examples are given in figs. 96 to 98, for a superfamily (96*a*), two families (96*b*, 97) and a genus (98).

It will be noticed that these curves exhibit a certain regularity. One (fig. 97) has a protracted initial *lag phase* which was too short in the other instances to appear in the graph.[2] All curves show a period of *progressive* rise which is suggestive of a logarithmic increase

[1] Such figures, of course, are not meant to be exact.

[2] It would have appeared if the earliest time-interval had been subdivided further.

(*increase phase*). It is followed by the climax, or *stationary phase*, which is short in the curves shown but may be protracted (fig. 95, Chondrostei). The subsequent *phase of decline* may be sudden (figs. 97, 98) or slow (fig. 96*b*). The terms here used are taken from

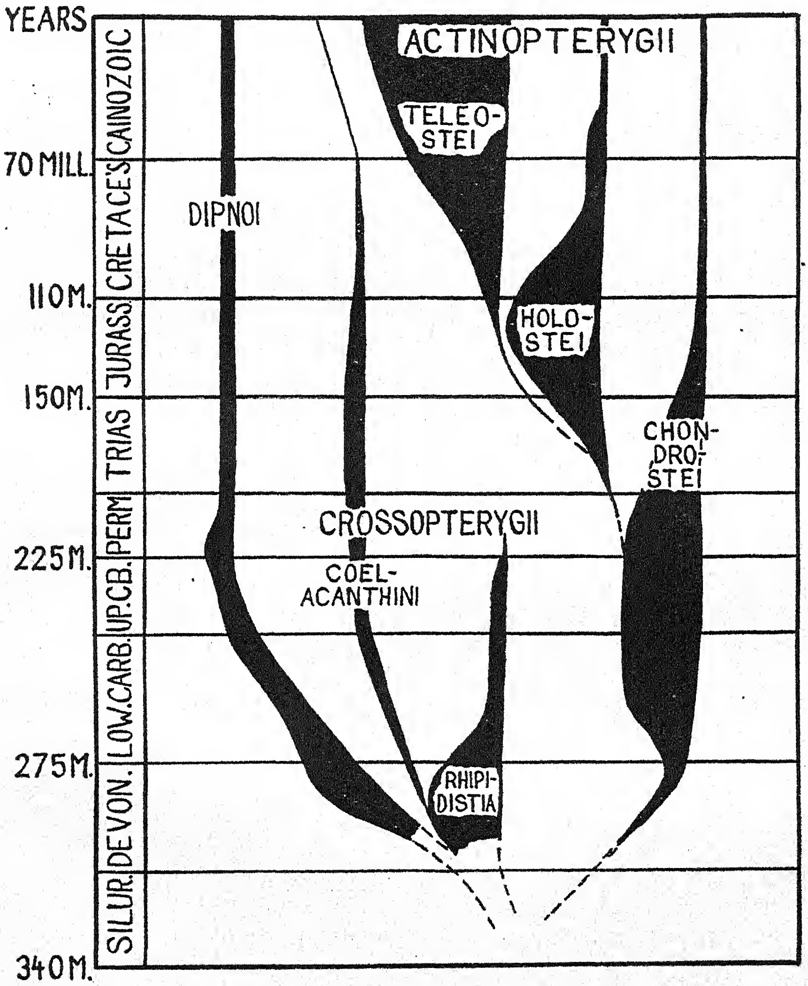


FIG. 95.—Phylogenetic tree of the fishes, plotted on the time-scale.—After Romer (1933), modified.

another kind of time-frequency curve which shows the increase and decrease of population in a colony of bacteria (fig. 99, Corbet, 1934).

These curves are nothing but an expression of what is sometimes called the Law of Organic Growth. The logarithmic shape which the lag and increase phases tend to approach indicates an under-

lying exponential function or, expressed in simpler terms, one in which the increase per unit is determined by a certain constant factor of multiplication.

Let us take the example of successive generations of a species and assume that there are one hundred individuals, 50 males and

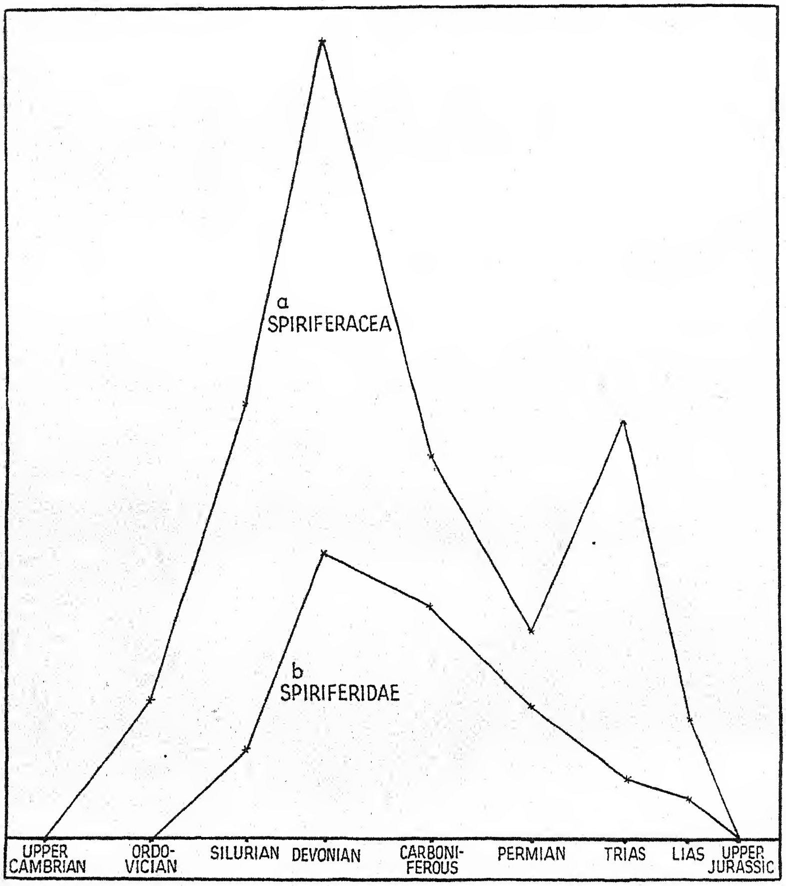


FIG. 96.—Time-frequency curves of Spiriferacea (Brachiopoda). (*a*) Super-family Spiriferacea ; (*b*) Family Spiriferidae. Note the two maxima of curve (*a*), which indicate its composite nature. Method of plotting : Horizontal, time-scale marked at distances in correct proportion to the radioactivity time-scale. Vertical, number of genera.

50 females, to start with. If only one hundred individuals out of their progeny reach maturity and the same occurs in every successive generation, the multiplication factor is 1, and the time-frequency curve would be represented by a straight, horizontal, line. If more than one hundred individuals survive, the curve will rise and do

so increasingly, in the later stages at a very rapid rate. The following table shows this:

Multiplication factor	Initial number of individuals	Generation								
		2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	100	100	100	100	100	100	100	100	100	100
1·5	100	150	225	348	521	782	1,173	1,759	2,639	3,958
2	100	200	400	800	1,600	3,200	6,400	12,800	25,600	51,200

A slight advantage of a species over its environment, resulting in a survival rate only just over 1, will, if the advantage persists for some time, result in a logarithmic rise of the number of individuals. *Mutatis mutandis* the same applies to any increase in the number of organisms in the course of time.

If a curve shows two maxima (fig. 96*a*), it is to be suspected that two stocks have been combined. In our instance, the maximum in the Devonian is that of the Spiriferidae, and the second in the Trias that of the 'diplospiral' Athyridae and the closely related Koninckinidae.

Time-frequency curve and rate of production of new types. Now it is clear that the episode of abundant production of new types, previously discussed, is largely coincident with the phase of logarithmic increase. The peak of the time-frequency curve is reached when the number of extinctions equals the number of newly-formed types. This may occur (*a*) because the rate of production of new types diminishes, or (*b*) assuming this rate to persist unchanged, because an external, environmental factor increases the rate of extinction. The fact that the peak or stationary phase was reached after a time of less than 100 million years in all cases investigated so far, suggests that these limiting factors come into action quite normally. The causal constituents of these factors cannot be discussed in the present context, fascinating though such speculations may be. But it is necessary to indicate one other numerical feature emerging from this limitation of the phase of logarithmic increase.

If we arbitrarily assume that at the beginning of the phase of increase there was a single species in existence, that for some unknown reason this species splits into two in the course of one million years, and that the descendant species again each split into two in the second million years, and so forth—in other words if the numerical rate of species evolution is 2 per million years, there would be something like 1,130 billion species about after 50 million years. This absurd figure shows that, in the practice of nature, either the numerical rate of species evolution is much less than two in one million years, or natural selection extinguishes many species, even in such instances of explosive evolution as have been used in the

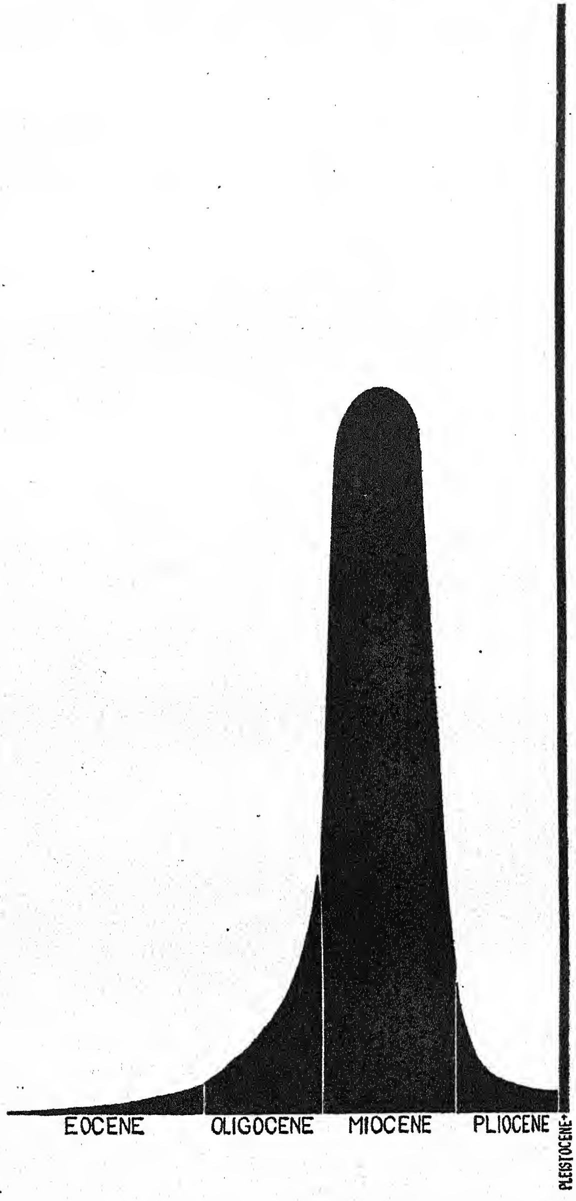


FIG. 97.—Time-frequency curve of the Family Clypeastridae (sea-urchins, Echinodermata). 250 fossil, 22 Recent (Pleistocene) species.—Material taken from Lambert and Thiéry (1925).

Method of plotting: *Surface area* proportional to number of species known from period in question. The difference between Pleistocene and late Pliocene illustrates the incompleteness of the palaeontological record, but this disadvantage applies more or less equally to all periods prior to the Pleistocene.

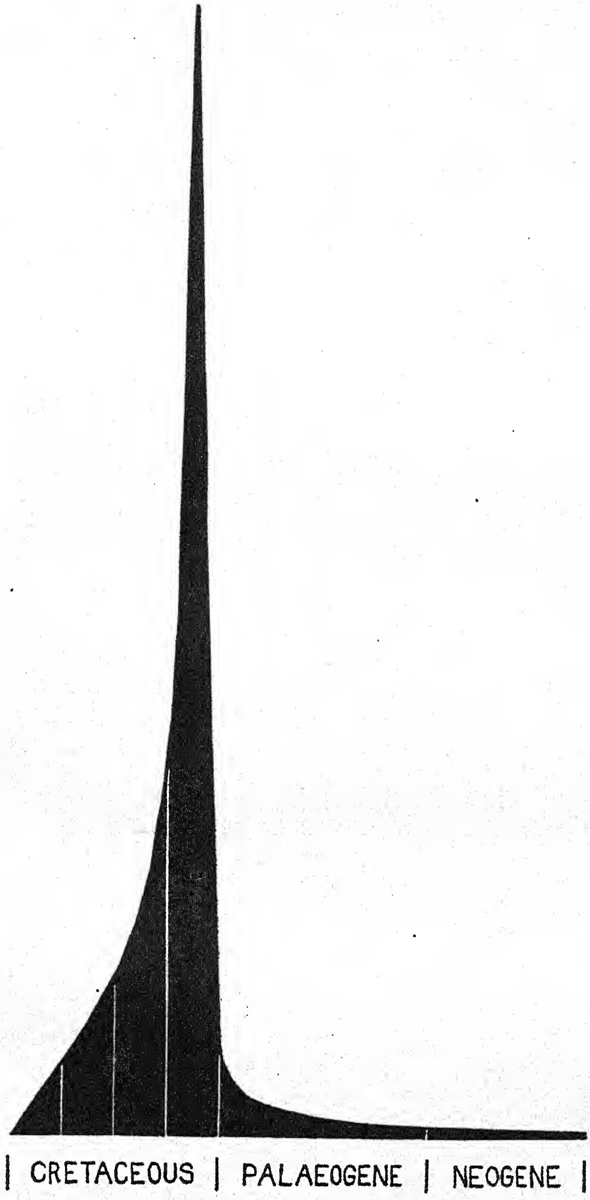


FIG. 98.—Time-frequency curve of the genus *Salenia* Gray (sea-urchins, Echinodermata). 76 fossil (and 4 Recent) species.—Material and method, see fig. 97.

present argument. Reasonable figures, which agree with the number of species of Recent, plastic, groups such as certain insects, are obtained if the rate is assumed to be for instance 2 surviving species in 5 million years, when after 50 million years about 1,000 species will exist.

Although these figures are highly conjectural, they suggest to me that the rate of species evolution is subject to certain peculiar limitations, and that the production of new species is a comparatively slow process, of the order of one or a few million years. This point, however, can be tested from a different angle, namely that of the time which was required for the evolution of certain species in the past.

Explosive evolution. Summary. Before attacking this problem,

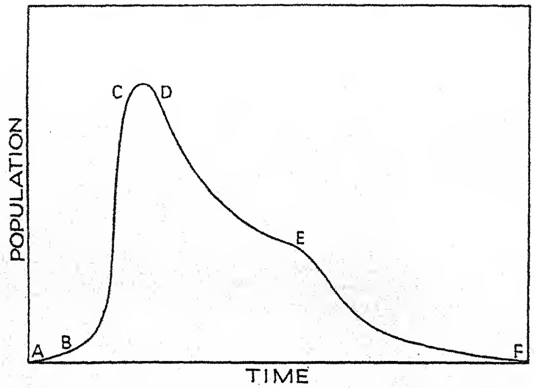


FIG. 99.—'Bacterial growth-curve,' of the population of a bacterial colony growing on a culture-medium, plotted against time. A–B, lag phase. B–C, logarithmic increase phase. C–D, stationary or critical phase. D–F, decline phase.—After Corbet (1934), with permission.

let us briefly summarize the main conclusions concerning the problems discussed up to this point.

(1) In the evolution of any stock there may occur, and have occurred, episodes of abundant production of new types. These episodes lasted for several tens of millions of years; as a rough average, 50 million years may be taken.

(2) The episodes of explosive evolution result in a logarithmic increase of the number of species (and genera), the rate of production of new forms being greater than the rate of extinction. The peak is reached when these two rates become equal, and the subsequent decline may follow various lines.

(3) The rate of species-production to be computed from explosive evolution is surprisingly low, being probably of the order of two new surviving species from each ancestral species in 5 million years.

C. THE TIME-RATE OF SPECIES-EVOLUTION

Time-rate of species-formation. Quite apart from the bearing the rate of species-formation has on the problem of explosive evolution, it is in itself a most interesting subject, to which geochronology has contributed an essential basis.

The faunas of the Pleistocene and post-Pleistocene and, to a minor degree, of the Tertiary, provide chances of determining how much time was actually taken by certain processes of species-formation.[1] In selecting examples, I have attempted to draw upon some widely different stocks, namely the mammals, the insects and the marine mollusca, in order to obviate the argument that any results obtained apply to one group only. Terrestrial groups are much more suitable than marine ones, since their ecology is better known and their response to environmental changes more obvious.

Post-Pleistocene evolution. The changes in the characters of species which have occurred after the Last Glaciation (i.e. roughly in the last 10,000 to 20,000 years) are slight everywhere. As far as this can be tested by fossil material, many species indeed have not altered to a noticeable degree, or so little that even a subspecific distinction is impossible. In some, however, the degree of differentiation is somewhat higher.

British Red Deer. An interesting case is that of the British race of the red deer (*Cervus elaphus scoticus* Lönnberg). It is smaller than the continental race (*C. e. germanicus* Desmarest) which ranges from France to Russia, and the antlers are less developed. In

[1] It will be noticed that, on the following pages, the terms 'species' and 'subspecies' are used as if they designated unambiguous and clear-cut units. I am fully aware that this is not so. In naming species and subspecies, authors are (or ought to be) guided by their experience with the Recent fauna, in which species are forms, or groups of forms, which are not linked by intermediate forms with their nearest allies, and which would not freely and successfully interbreed even if intermingled. This latter point is, of course, nearly always an assumption, but systematists will agree that the cases in which the distinction of species is difficult are, on the whole, few compared with those which are clear.

The palaeontological species should, morphologically, be treated as if it were a Recent species. In other words, within the same stratigraphical level or at any one moment of the chronological scale, the fossil forms should be treated as if they were members of a Recent fauna, with their individual and geographical variation.

The palaeontological species is, however, more than this, being also a species in time, representing a section of the lineage and affording no clear delimitation along the lineage. In separating species in time, the measure of variation known to occur in related Recent species is usually applied, and if the morphological differences between two sections of the lineage are greater than those of Recent species, different specific names are used.

Authors vary in their conception of the scope of the term 'species', and a species of one may be regarded as a subspecies by another, and as a species-group by yet another author. But the differences of opinion rarely exceed this amount. On the whole, therefore, the term 'species', though vague in several respects, has in practice proved to provide a workable basis for the definition of forms of life. See also Zeuner (1943).

particular, the bez-tine is, as a rule, missing (Zeuner, 1939). *C. e. scoticus* shares this character with other subspecies found along the western edge of the area of *C. elaphus Linné,* namely with *C. e. atlanticus* Lönnberg which occupies an isolated strip of country on the west coast of Norway up to 65° N. lat., *C. e. hispanicus* Hilzheimer from Spain, *C. e. corsicanus* Erxleben from Sardinia and Corsica, and *C. e. barbarus* Bennet from northwest Africa.[1]

All the fossil remains, however, of British red deer known to me, including those of the Last Glaciation and many of the early Postglacial, are large and their antlers identical with the continental type, being strongly developed and possessing the bez-tine. Up to the Atlantic period, Britain was connected with the Continent, so that this observation is not surprising. It is only since the severance of Britain from the Continent (see p. 97) that the characters of *C. e. scoticus* have developed, i.e. within the last 7,500 years.

The subspecific characters of *C. e. scoticus* are correspondingly unstable. The form crosses readily with *C. e. germanicus* and other subspecies and assumes their characters; the bez-tine is present in many British stags for this very reason. Scottish deer imported into New Zealand developed into a race as large and strong as the Carpathian race (Huxley, 1932, p. 205). In short, 7,500 years have, in the case of *C. elaphus,* produced a purely phaenotypic geographical subspecies.

It is interesting to note that the evolution of *C. e. scoticus,* distinguished from the Continental race chiefly by degenerative characters, finds a parallel in the appearance of a similar, but still smaller, almost minute, race of *C. elaphus* in the Last Interglacial of Jersey, Channel Islands (*C. e. jerseyensis* Zeuner, 1939, 1940*a*). This island was detached from France during the Last Interglacial as it now is, and the period of isolation cannot have exceeded 70,000 years and probably was considerably shorter. The morphological differences are, in this case, much greater than in that of *C. e. scoticus* and extend to the bones of the feet also. It is safe to say that the period of isolation of *C. e. jerseyensis* was longer than that of *C. e. scoticus* and that, correspondingly, the morphological differences evolved are greater.

Large Copper butterfly in England. Another instructive case is that of *Lycaena dispar dispar* Haw., the famous Large Copper Butterfly of England (Edelsten, 1929; Riley, 1929; pl. XXII, fig. B). This race is now extinct, but the number of specimens preserved in collections is sufficiently large for a comparison with the various forms occurring on the Continent of Europe and in Asia. The species is found from western France (Bordeaux) through Germany, Austria, Balkan Peninsula, Russia (south Russia, Podolia, Vyatka), the Caucasus, Semipalatinsk, the southern Altai, Tibet, northwest

[1] For races of *C. elaphus,* see Miller, 1912.

China, Manchuria and Korea to the Amur Province, but is everywhere local, depending on dense patches of the water-dock (*Rumex hydrolapathum* Huds.) and related plants in swampy districts. In England, it occurred in the fens of Cambridgeshire and Huntingdonshire (see p. 89) which are young land formed during or since the Atlantic phase of the Postglacial.[1] The English *L. d. dispar* Haw. resembles very closely the Dutch *L. d. batavus* Oberth. from Friesland and St. Quentin (Aisne, north France), and cross-breeding between this and the German subspecies, *L. d. rutilus* Wern., has been carried out without the slightest difficulty.

The fact that *L. d. dispar* and *L. d. batavus* resemble one another so closely that they can usually be separated in series only, whilst they are both more readily distinguished from *L. d. rutilus*, suggests a common origin, as does their geographical distribution. Their common ancestor would have lived in the once frequently flooded, but now entirely submerged, area of the lower Rhine, which forms the western part of the North Sea. This area was land in the Boreal phase of the Postglacial. On the other hand, glacial and periglacial conditions would have excluded *L. dispar* from the area until well after the Last Glaciation. If we therefore estimate its immigration into this area at 15,000 years ago, $\pm$ a few thousand years, we are not likely to be far off the mark. This time would have sufficed for the evolution of the differences compared with *L. d. rutilus*, and the 7,500 years of separation from Holland would account for the slight differences between the British and Dutch races. The characters involved are restricted to the coloration; between *L. d. rutilus* and *L. d. batavus* + *dispar* they extend to the shade of the pigmentation, whilst between *L. d. batavus* and *L. d. dispar* they are confined to the relative size of dots and bands.

Subspecies of insects on Jersey, C. I.; Platycleis occidentalis. A third instance of subspecific differentiation during the Postglacial takes us back to Jersey. From this island, several indigenous subspecies have been described. Of these, *Platycleis occidentalis jerseyana* Zeuner (1940*b*), a tettigoniid grasshopper, is well distinguished in size, proportions and shape of the ovipositor from the form *P. o. occidentalis* Znr. which occurs in France, west Germany and southern England.

The isle of Jersey lies on a submerged platform and was connected with France until late in Boreal times. The separation, due to the rising sea-level of the Flandrian transgression, is not likely to have occurred more than 10,000 years ago, and not later than 7,000 years ago. Since *Platycleis occidentalis* is a species which cannot have lived in Jersey under the periglacial climate of the Last Glaciation,

[1] This was the only district where the form was frequent. It appears also to have occurred in similar places in Norfolk and Suffolk, and in Somerset (Hudd, 1906).

it must have immigrated into Jersey early in Postglacial times. 7,000 to 10,000 years were therefore sufficient for the evolution of the pronounced characters of the subspecies *P. o. jerseyana*.

It is important to note that British individuals of *P. occidentalis* do not differ from continental ones, although the separation of Britain from the Continent occurred hardly, if at all, later than that of Jersey. In Britain, however, the species is restricted to a few colonies on and near the south coast, and the British climate, unlike that of Jersey, is little suitable for a *Platycleis*, the genus being almost entirely mediterranean in distribution. *P. o. jerseyana* thus appears to illustrate well the rapid evolution of forms on small islands under favourable environmental conditions, a case which has been observed in other groups and regions also.

A second instance is that of the acridid grasshopper *Euchorthippus elegantulus* Znr., also from Jersey. This is most probably a subspecies of *Eu. declivus* (Bris.) but, the precise status of the species and subspecies of the genus still being obscure, the Jersey form is temporarily treated as a species from the classificatorial point of view. The characters which distinguish it from its nearest allies are of subspecific value.

The Jersey Shrew, Sorex araneus fretalis. Among the vertebrates of Jersey, the shrew, *Sorex araneus* L., distributed over the temperate and northern portions of Europe and Asia, occurs in a distinct subspecies (*S. a. fretalis* Miller, 1909 ; Miller, 1912). At first sight, this appears to be another instance of Postglacial differentiation on Jersey. Whilst the two insects described, however, are southern forms which would not have survived a periglacial climate on the spot, this little shrew may have persisted on Jersey through the Last Glaciation, and its subspecific differentiation may, therefore, date from the Pleistocene.

On the whole, the vast majority of species appear to have remained unaltered during the last 10,000 or 20,000 years representing the Holocene or Postglacial. As shown in the preceding paragraphs, however, some instances have been found of subspecific differentiation within about 7,500 years or slightly more.

This conclusion is corroborated by Moreau (1930) who found that some subspecies of birds in Egypt were formed in 5,000 to 10,000 years. Huxley (1942, p. 194) subscribes to this view and quotes a number of further instances in which even a few hundred years have produced morphological differences. Whether all these instances deserve to be considered as subspecific, and not merely as phaenotypic responses to environment, remains to be seen.

Pleistocene evolution. Insects from Starunia. Turning now to the Pleistocene, it is advisable first to consider the later part of this period, comprising the Last Glaciation and the Last Interglacial ('upper Pleistocene'). An insect fauna dating from the Last

Glaciation was discovered at Starunia, near Stanislawow, in the Polish Carpathians. It was found associated with bodies of the woolly rhinoceros and the mammoth (Nowak, Stach, &c., 1930; Zeuner, 1934*a*, *b*, 1945). The fossils were preserved in a 'pickled' condition, being contained in a silt soaked with salt and mineral oil. They could be studied almost like Recent specimens.

Grasshoppers figured prominently in this fauna. Out of these, four were so well preserved as to allow of a detailed comparison with modern races. One of them, *Melanoplus frigidus* (Bohem.), was completely identical with Recent European specimens. One, *Podismopsis gracilis pleistocaenica* Znr., is certainly, and another, *Gomphocerus sibiricus* (L.), probably, subspecifically distinct from Recent forms. One, *Stenobothrus posthumoides* Znr., is at least subspecifically, if not specifically, distinct from its nearest Recent relative.[1]

Podismopsis gracilis pleistocaenica is, geographically and morphologically, the link between *P. g. gracilis* F.-W. of central Asia and *P. g. relicta Rmme.* of Montenegro. It may be ancestral to the two modern subspecies. On the other hand, it constitutes with them a geographical subspecies-group with gradually changing characters, and it is conceivable that the characters of the two Recent subspecies were, in the upper Pleistocene, as clearly differentiated as they are now, so that all that happened was the extinction of the central member of the subspecies-group. In either case, the distinction of the forms involved has not exceeded subspecific characters since the upper Pleistocene.

The time involved in these processes may be assessed at not more than about 100,000 years and not less than 20,000 years, according to the phase of the Last Glaciation during which the Starunia deposits were formed. This phase cannot be ascertained at present.

Upper Pleistocene mammalian faunas. An analysis of mammalian faunas of upper Pleistocene age,[2] such as that of the Younger Loess, for instance Wallertheim (p. 159) or Předmost, of the cold phases of the Last Glaciation, or of Cotencher in Switzerland or Ehringsdorf in Thuringia (p. 159) of Last Interglacial age, show that, apart from a number of forms whose lineages are now extinct, there are nothing but Recent species. The differences observable in osteological material are so slight that authors have often hesitated to introduce even a subspecific distinction. Yet, in many species, slight differences do exist which, in the eyes of systematists working on Recent material would be regarded as of subspecific value.[3] It

[1] The affinities of the members of this fauna are discussed in Zeuner (1941–2).

[2] For mammalian faunas of Pleistocene age and faunal evolution during the Pleistocene, compare Zeuner, 1944, Chapter X.

[3] This also applies to *Microtus anglicus* Hinton, *Dicrostonyx henseli* Hinton and some other rodents of the upper Pleistocene which, as a matter of convenience, are usually quoted as 'species'.

is important to note that, in spite of abundant fossil material, no new species is known to have arisen since the Last Interglacial. 150,000 years have not produced any new species among the mammalia of Europe, though a fair number of subspecies appear to have arisen during this period.

Pleistocene marmots. An instructive example has been supplied by Wehrli (1935). He studied the marmots of the upper Pleistocene and found that both the Alpine marmot (*Marmota marmota* (Linné)) and the bobak or steppe marmot (*M. bobak* (Müller)) of Russia and northern Asia are present in the upper Pleistocene of the German lowlands. The fossil form of *M. marmota* is larger than the Recent Alpine form, in the average by 10 per cent. Osteological differences are slight, the most marked being in the shape of the temporal ridges. In all marmots, except the Recent *M. marmota* and a certain number of fossil specimens, the temporal ridges of the skull run into the upper posterior edge of the processus postorbitalis, whilst in Recent *M. marmota* it has moved on to the upperside of the processus. This character was not yet fixed in *M. marmota* of the upper Pleistocene, but has become almost entirely stable since. This is shown by the following figures drawn from Wehrli's paper:

Horizon and Locality	Temporal ridges			No. of skulls studied
	Marmota-type	Inter-mediate	Primitive type	
Last Glaciation: Niedermendig, Rhenish Schiefergebirge	33%	53%	13%	30
Recent: Alps	98%	—	2%	120

These and other characters confirm that the upper Pleistocene *Marmota marmota* can be regarded as ancestral to the Recent form, but the differences between them are merely in the degree of perfection of characters, and there is a considerable overlap in the curves of variation of these characters. Forms of this degree of variation would, in the Recent fauna, be regarded as subspecies.

Similarly, the fossil bobak differs from the Recent form in the degree of development of minor features, among them in the average shape of the foramen magnum. This character, too, may be regarded as subspecific, if at all so, and most certainly not as specific.

The common origin of the two closely related species, *M. marmota* and *M. bobak* (and others of the genus *Marmota*) lies further back than the Last Interglacial, since *M. marmota* has been found in deposits of this phase situated in the Alps.[1]

[1] Another instance of the same category as the marmot is that of the mountain suslik of the Caucasus (*Citellus musicus musicus* Ménét), which, however, is not supported by fossil evidence. It was described by Sviridenko (1927) and is of

Middle Pleistocene fauna. Ibex. The fauna of the middle Pleistocene (Penultimate Interglacial and Penultimate Glaciation) is less well-known than that of the upper or of the lower Pleistocene. Only one instance, therefore, can be quoted here in detail, that of the ibex.

The ibex (*Capra ibex* Linn.) is, at the present day, a mountain goat. It occurs in the Alps (*C. i. ibex* Linn.), the Pyrenees and some Spanish mountains (*C. i. pyrenaica* Schz.), central Asia from the Himalayas north to the Altai (*C. i. sibirica* Pall.), the Caucasus (*C. i. severtzowi* Menzb.), and Sinai, Palestine, southern Arabia and Abyssinia (*C. i. nubiana* Cuv.). These major geographical units have been considered as species (for instance, Lydekker, 1913) and subdivided into a large number of local races. More recently, Schwarz (1935) has claimed that the differences do not justify a specific distinction, and that the Arabian-Abyssinian group even shows signs of grading into *Capra hircus* Linn., the wild goat of the Mediterranean area. The entire assemblage of *C. ibex* + *hircus* bears the marks of a subspecies-group (= *Rassenkreis* of Rensch) in which the extreme members are as different as species in other cases, but these extremes are connected by transitional forms. For the present purpose it should be kept in mind that the subspecies enumerated above are well-distinguished and differ more widely than do, for instance, the Postglacial subspecies of *Lycaena dispar* (Linn.) (p. 364).

During the cold phases of the Pleistocene, the ibex occurred at low altitudes all over Europe, from Spain (Gibraltar) through France (Mentone), Germany (Thuringia), Italy (Apulia, see p. 223), Moravia (*Capra prisca* Woldřich 1893; not identical with *C. prisca* Adametz 1914), to the Balkan Peninsula.

In 1934, Toepfer described as *C. camburgensis* an ibex from a Thuringian gravel terrace of the first phase of the Saale Glaciation to which, on the astronomical time-scale, an age of about 230,000 years is assigned. Toepfer came to the conclusion that 'the combined occurrence in *C. camburgensis* of characters which, in the upper Pleistocene, are found in different forms of the ibex is best explained if one considers the Camburg ibex as the ancestral form'. Since the diagnostic characters of *C. camburgensis* are within the range of variation of the subspecies-group of *C. ibex*, it is clear that *C. camburgensis* is not an ancestral *species* (as it is called by Toepfer), but an ancestral form only *subspecifically* distinct from its Recent relatives (correctly, therefore, *C. ibex camburgensis* Tpf.). The

particular interest because the mountain subspecies differs from that of the plains (from which it is separated by a wide gap) in habits as well as morphological and physiological characters. It is considered to have lived in the mountains during the Last Glaciation, since the re-immigration of the plains subspecies in Postglacial times from the east can be traced in some detail.

evolution of the Recent subspecies of ibex, therefore, has required at least some 230,000 years.

Lower Pleistocene faunas. Turning now to the faunas of the lower Pleistocene (Early Glaciation, Antepenultimate Interglacial, Antepenultimate Glaciation), the perusal of lists for any locality (for instance, Forest Bed, Mauer, Mosbach, Tegelen ; Zeuner, 1944, pp. 259–262) reveals a great difference in composition as compared with the faunas of the upper Pleistocene. Apart from a fair number of species belonging to lineages which have since died out or are too little known to be studied phylogenetically, many Recent species are represented by forms designated by the authors either as subspecies or even as species. The number of lower Pleistocene mammals which cannot be (or have not yet been) distinguished from their Recent descendants is small. In the Forest Bed of East Anglia (Antepenultimate Interglacial) it is 14 per cent., in Mosbach (late Antepenultimate Interglacial or early Antepenultimate Glaciation) 31 per cent., in Mauer (interstadial of Antepenultimate Glaciation) 37 per cent. These figures demonstrate clearly that in many lineages of European mammalia changes of at least subspecific value have occurred since the lower Pleistocene. The deposits referred to are, according to the astronomical scale, about 450,000 to 600,000 years old. This period of time, therefore, was sufficiently long for many subspecies and some species of mammalia to evolve.

Pleistocene elephants. As a particularly instructive example, the lineages of the Pleistocene elephants of Europe may be described here. They were reconstructed in great detail by Soergel (1912) and have since been confirmed and improved upon by many authors (for details and references, see Zeuner, 1944, p. 275).

Of the morphological changes which occurred in the lineages of the elephants, those in the structure of the molar teeth are most easily studied, since elephants' teeth are not only frequent fossils but were also affected, in the course of evolution, by the diet of the animals and, therefore, indirectly, by the environment in which they lived. The molars of elephants are composed of upright lamellae which appear in cross-section on the grinding surface (fig. 100). The number of the lamellae increases in the course of phylogenesis, and they become narrower in cross-section.

The ancestor of the European Pleistocene elephants is *Elephas meridionalis* Nesti (pl. XXIII, fig. A), from the upper Pliocene (Villafranchian). This species had a wide range of distribution and varied considerably. It persisted into the earliest Pleistocene (Forest Bed, Mosbach), and this latest form, which grades into the primitive representatives of the *primigenius-* and *antiquus-*lineages (see following paragraph) may be called *E. meridionalis nesti* Pohlig. This name is based on specimens from the East Anglian Forest Bed.

The lamellae of the molars of *E. meridionalis* are few, and wide in cross-section (fig. 100).

The range of variation of *E. m. nesti* of the Antepenultimate Interglacial is larger than that of the typical *E. meridionalis* of the Villafranchian, and extreme varieties appear with rhomboidal lamellae, resembling the later *E. antiquus,* and others with narrower and little widened lamellae, reminiscent of the later *E. trogontherii.* Single specimens of this kind would be, and have been, determined as belonging to the above-mentioned elephants of the middle Pleistocene, but in the lower Pleistocene they are merely the rare, extreme, variants of an intermediate, ancestral, form. The intermediate

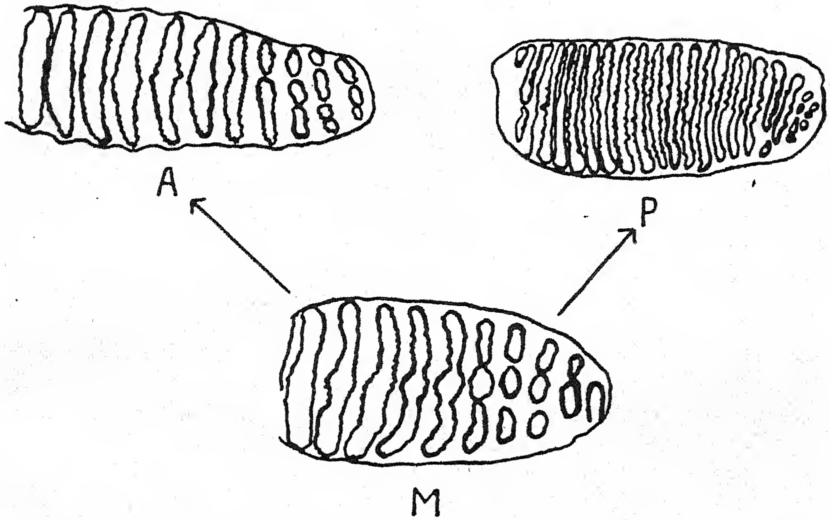


FIG. 100.—Diagrams of grinding surfaces of molars of *Elephas meridionalis* (M), *E. antiquus* (A) and *E. primigenius* (P), showing specialization in the course of the Pleistocene.

specimens are far more frequent than the extremes, and the former, therefore, represent the average characters of the species of that phase.

The earliest record of a *trogontherii*-like variant of the *meridionalis*-stock is from Italy and presumed to come from the Villafranchian. The earliest specimens of the *antiquus*-type appear at the time of the Early Glaciation in England.

In the course of the lower Pleistocene a degree of ecological differentiation becomes apparent. In the Forest Bed (Antepenultimate Interglacial) the relative frequency of the variants still agrees with the normal variation curve, intermediate specimens being the most frequent. In Mosbach (late in the same Interglacial) *trogontherii*-like specimens dominate, and *antiquus*-like specimens are rare. In

Mauer, however, whose fauna is one of woodlands (Interstadial of Antepenultimate Glaciation), only *antiquus*-like specimens have been found. Again, in Süssenborn (probably second cold phase of Antepenultimate Glaciation) *trogontherii*-like molars only have been recovered.[1]

In the middle Pleistocene, the two lineages appear more clearly separated, and intermediate specimens vanish from central Europe, though they linger on in southern France. In *E. trogontherii*, the lamellae of the molars continue to become more numerous and narrower in cross-section, and in deposits of the Penultimate Glaciation specimens occur which are reminiscent of the mammoth, *E. primigenius*, of the upper Pleistocene. It is difficult to say when exactly the *primigenius*-stage was reached, but with the beginning of the upper Pleistocene (Last Interglacial) the *trogontherii*-like specimens disappear from the scene.

E. primigenius continues to follow the described evolutionary trend throughout the upper Pleistocene, and the molars of the very latest specimens have extremely narrow, tightly packed and numerous lamellae. The species seems to have persisted up to the last phase of the Last Glaciation, which means that there were mammoths still living in central Europe only about 18,000 years ago. As I have mentioned elsewhere (Zeuner, 1935), molars of the latest evolutionary type were dredged from the Oder near Breslau and show an alluvial kind of preservation, so that *E. primigenius* possibly lasted even into the earliest Postglacial. The bodies of mammoths found frozen in ice in northern Siberia also exhibit advanced characters and therefore may date from the earliest Postglacial (rough estimate, 15,000 years ago).

The upper Pleistocene mammoth was a very distinctive species of elephant, with many peculiar characters, especially in the shape of the skull, dentition, loss of a toe, and coat of hair (pl. XXIII fig. C). Taxonomically it was a clearly-defined species.

The lineage of *E. antiquus* Falc. (pl. XXIII, fig. B) developed the rhomboidal shape of the lamellae. Their number also increased, but more moderately than in the *primigenius*-lineage. This is in accord with the ecology of the species, *E. antiquus* remaining associated with woodlands and parklands, whilst *E. primigenius* became adapted to the specialized environment and the harder food of the open steppe and tundra.

E. antiquus does not appear to have survived into the Last Glaciation.[2] It still occurred in Ehringsdorf, late in the Last Inter-

[1] In the upper Pleistocene, the ecological divergence of the two lineages is very pronounced, *E. primigenius*, the descendant of *E. trogontherii*, being found chiefly associated with steppe faunas of the loess steppe or tundra during the cold phases, *E. antiquus* with woodland faunas, mostly of the interglacial type.

[2] Except in the Mediterranean region.

glacial. Dietrich says that the teeth of *E. antiquus* from the Rixdorf horizon (one of the interstadials of the Last Glaciation) are probably derived from an earlier interglacial.

In short, the upper Pliocene *E. meridionalis*, an unspecialized species which occurred in a variety of habitats ranging from woodlands to bush-steppe or savannah, developed in the course of the Pleistocene into two different species, one adapted to woodlands and a temperate or warm climate (*E. antiquus*), and the other to open steppe and tundra, harder food and a colder and more continental climate. This divergent evolution became apparent soon after the first cold phases of the Pleistocene had occurred, i.e., during the Antepenultimate Interglacial. At that time, however, the vast majority of specimens were still of an intermediate character (*E. meridionalis nesti* Pohl.).

During the Antepenultimate Glaciation, the differences became more marked; though intermediate specimens still occurred. In the number of specimens, two frequency-maxima had developed, one with *trogontherii*-characters and another with *antiquus*-characters. At the same time, the *trogontherii*-type is observed to occur more frequently in steppe or glacial habitats, and the *antiquus*-type in woodland, interglacial or interstadial habitats, though not yet exclusively so.

By the end of the middle Pleistocene and the beginning of the Last Interglacial, the intermediate forms had disappeared nearly everywhere, and two morphologically and ecologically distinct species had emerged. Since the environment favoured by *E. primigenius* spread periodically over central and west Europe during the glacial phases, whilst that of *E. antiquus* reigned during the temperate inter-phases, the two species alternate stratigraphically in the later Pleistocene successions of central and west Europe, *E. primigenius* probably withdrawing to the north-east in the mild phases, *E. antiquus* to the south in the cold phases. Where their environments met or overlapped, their remains are found associated in one deposit, though as distinct species. Intermediate specimens are absent from the upper Pleistocene.

Considering this instance of divergent evolution, one is inclined to link causally the process of species-formation with the climatic fluctuations of the Pleistocene. The time required for the evolution of two species from their common ancestor was, in this case, about 500,000 years, counting from the first evidence of incipient divergence in the Villafranchian to the clear establishment of two unconnected species in the Last Interglacial.

Instances of suggested differentiation of species during the Pleistocene. The instance of the Pleistocene elephants has been described in some detail, since it is so far the case of species-evolution most completely supported by direct evidence. There is, however, plenty

of evidence that many other species, at any rate in Europe, have developed in the course of the Pleistocene and most probably in connexion with the climatic fluctuations and repeated displacements of the main environmental zones (see Zeuner, 1944, p. 276). Many authors have inferred from the present geographical distribution that, for instance, the area of certain ancestral species was split into two or more 'refuge' areas by the ice-sheets of the glacial phases, and this is indeed likely to have happened since, in the narrow unglaciated strip between the Scandinavian and Alpine ice-sheets, a severe periglacial climate prevailed which was probably unsuitable for many species requiring temperate conditions. This repeated cutting of a continuous area into an eastern (or south-eastern) and a western (or south-western) refuge area may have produced eastern and western subspecies or species, which would now meet or overlap in central Europe.

Carrion Crow and Hooded Crow. A good example is that of the carrion crow (*Corvus corone* L.) of western Europe and the hooded crow (*Corvus cornix* L.) of northern, east and south Europe including Italy (Meise, 1928). Except in winter, when the hooded crow tends to go westwards, the overlap is confined to a narrow line from Jutland south to the Alps and thence along the Alps to their western end; Italy, Corsica and Sardinia belonging to the area of the hooded crow. The extreme narrowness of the zone of frequent overlap suggests that hybrids are not infinitely fertile, so that the two forms must be regarded as species. Both have already begun to develop geographical subspecies in their respective areas.

The tettigoniid grasshoppers Platycleis grisea and occidentalis. An almost identical case is that of the tettigoniid grasshoppers *Platycleis occidentalis* Znr. and *P. grisea* Fab. (Zeuner, 1931*a*, 1941*a*), which overlap in precisely the same manner as *Corvus corone* and *C. cornix*. In both instances the affinity of the two species to one another is closer than to other species of the same genus, and this in conjunction with the geographical distribution renders it highly probable that they evolved as geographical forms of some ancestral species.

The theory of geographical differentiation of subspecies in consequence of the climatic fluctuations of the Pleistocene has in Recent years been widely applied, as for instance by Rensch (1929), Reinig (1937), who studied birds and insects, and Eller (1936) who reconstructed the history of the races of the swallowtail butterfly, *Papilio machaon* L. It is incorporated in the recent syntheses of evolution by Huxley (1942), and Mayr (1943).

Examples of this kind show that a certain number of species are likely to have arisen from ancestral forms during the Pleistocene, i.e., within 600,000 years. But quite apart from this circumstantial evidence, direct palaeontological evidence, of which some instances

have been given above, proves beyond doubt that species did arise within this space of time. *No instance, however, is yet known of a species developing at a faster rate than that found in the elephants* (about 50,0000 years), and a comparison of this rate with those observed in the evolution of subspecies suggests that species rarely, if ever, have developed at a much faster rate than that of the Pleistocene elephants. A certain minimum time appears to be required for a lineage to advance from species to species.

Rate of evolution since the Tertiary. Pliocene Mammalia. In order to obtain some idea of the rate of species-formation previous to the Pleistocene, it will be useful first to consider some mammalian faunas of the uppermost Pliocene.

The fauna of the upper Val d'Arno in Tuscany (Major, 1884; Zeuner, 1944, p. 257) contains *Elephas meridionalis* and is, on the whole, only slightly more primitive than the fauna of the Forest Bed. It is considered as Villafranchian, dating from somewhere between 600,000 and one million years. The Val d'Arno fauna is probably just earlier than the Early Glaciation and therefore nearer the 600,000 mark. It contains no Recent species, except possibly the *Hippopotamus*, which occurs with what may be a distinct subspecies, *H. amphibius major* Cuv.

Other Villafranchian deposits contemporary with the Val d'Arno, such as Senèze (Stehlin, 1923), in France, contain no species or subspecies that have persisted unaltered up to the present day. As far as evidence goes, the mammalia of Europe have all changed their specific characters since the Villafranchian, or within the last one million years.

Rate of evolution of terrestrial forms. From the examples discussed in the preceding paragraphs, taken from groups as widely different as mammals and insects, it would appear that the rate of species formation in these terrestrial groups lies between 500,000 and one million years, and that very few species have existed unaltered for more than one million years.

Marine evolution. Mollusca. It may be argued at this point that terrestrial groups are liable to evolve at a faster rate than marine groups, since the latter live under more equable conditions and are less affected by frequent climatic fluctuations. If one calculates, for faunas of marine mollusca of lower Pleistocene and late Pliocene age, the percentage of forms which the authors have been unable to distinguish specifically or subspecifically from Recent species, one finds that the *average* rate of evolution was indeed much slower in the marine mollusca than in the mammalia. This is borne out by the table on page 376.

There is reason to believe that the Red Crag is contemporary with the Early Glaciation (see p. 181). The Coralline Crag is slightly older and, therefore, approximately contemporary with the mam-

East Anglian lower Pleistocene and late pre-Pleistocene	Percentage of Recent forms in the total number of forms known from each deposit *		
	Harmer	Boswell	Zeuner
Forest Bed (Antepenultimate Interglacial	—	90%	—
Weybourne Crag (?Early Glaciation, phase II)	89%	93%	—
Norwich Crag	89%	84%	—
Butleyan Red Crag } ?Early Glac. I	87%	73%	—
Newbournian Red Crag } ?Early Glac. I	68%		
Waltonian Red Crag	64%	67%	68%
Coralline Crag	62%	60%	—

* Newton, in Reid, 1890; Harmer, 1902; Boswell, 1928, 1931; Zeuner, 1937.

malian fauna of the upper Val d'Arno (Pilgrim, 1944, p. 36). Yet, while 60–67 per cent. of the marine species and subspecies survived to the present day, the known mammalia all underwent changes in the same space of time.

An even higher figure for survivals is found in the contemporary deposits of the Mediterranean Sea. The Calabrian phase of the Mediterranean is approximately contemporaneous with the Corralline Crag of south-east England and also with terrestrial deposits of Italy called Villafranchian (including the Val d'Arno fauna). On the basis of Gignoux's thorough work on the marine Pliocene and Pleistocene of Italy one finds that not less than 89 per cent. of the species and subspecies of the upper Calabrian Mollusca have survived to the present day. For the lower Pliocene (Astian + Plaisancian), the corresponding figure is 63 per cent.

Influence of environment on evolution. A comparison of these figures with those found for the English Crags suggests once more that the intensity of environmental changes increases the number of changes in the specific composition of the fauna. The area of the North Sea in which the Crags were deposited, was shallow and its coastline unstable, and it is certain that severe climatic fluctuations occurred repeatedly, affecting temperature and salinity of the water. In the Mediterranean, however, the corresponding fluctuations were much less intense.

Changes in the specific composition of a fauna are due both to extinction of certain forms and to the appearance of new ones. The latter class has again to be subdivided into immigrants and forms newly evolved on the spot. For obvious reasons it is difficult to sort out these groups in marine mollusca, and one cannot decide, therefore, whether the intensity of environmental changes is capable of speeding up the rate of evolution in any particular lineage. Lineages of terrestrial animals suggest that it is so, but this point cannot be cleared up by considering the average constitution of faunas. It necessitates a detailed study of lineages. Yet, it is conceivable

that species with a fast rate of evolution have an advantage over slowly-evolving forms when environmental conditions change frequently and considerably, so that the former are likely to prevail in the end and the latter liable to become extinct.

Stabilized species. The one fact that emerges with certainty from these comparisons of faunas is, that, in marine faunas, a large number of species and subspecies are stable, since they have not noticeably modified their characters since the late Tertiary. It is interesting, therefore, to see how long species can remain stable, or how far Recent species can be traced back in geological history.

Miocene of Java. Oldest Recent species. A suitable group of deposits are the Tertiaries of Java, studied, among many others, by K. Martin and Umbgrove (1933). The following table, derived from Umbgrove, is based on Martin's work:

Percentage of Recent species in Java	Local divisions	European equivalents
100%		Holocene
90%–80%		Pleistocene
70%–50%	Tertiary h	Pliocene
40%	Tertiary g	
30%–10%	Tertiary f	Miocene
0%	Tertiary e	
		Palaeogene

This table was built up on a fair number of localities, of which the most interesting in the present context is West Prongo, of lower Miocene age. It still contains 6·8 per cent. of Recent species. In earlier deposits, of upper Eocene and possibly Oligocene age, however, no Recent species have been found. On the radioactivity scale, the Miocene began about 30 million years ago, and this period of time may be regarded as the maximum period through which any species *is known* to have persisted without noticeable morphological modifications.[1]

A species, which has persisted from the lower Miocene to the present day without noticeable changes in its characters, must have a time-rate of evolution of astonishing slowness. It is extremely unlikely, however, that the change within its lineage was equally

[1] There is, of course, a possibility that very rarely a species persists through an even longer time. This applies perhaps to the brachiopod genus *Lingula* (see table, p. 351, row 12), but because of the scarcity of taxonomic characters in the shell this is difficult to prove. *Lingula* is discussed at some length in Davies (1937, p. 170).

slow in the more distant past since, if one assumes that it was so, some Tertiary molluscan genera would have existed as early as in the Palaeozoic, and this is plainly contradicted by the evidence.[1] At some time in the history of the lineage, the rate of evolution must have been faster. Later on, the characters became stabilized and the species continued to exist unaltered through many millions of years.

D. THE TIME-FACTOR IN EVOLUTION

In the two preceding parts of this chapter an attempt has been made to derive time-rates for certain evolutionary processes from the combination of palaeontological with geochronological evidence. This evidence is not yet complete enough to permit any far-reaching conclusions, but for the time being it is the only information available regarding the actual time that elapsed while species, genera, families and orders originated. It therefore deserves the attention of the student of evolution. For lack of evidence, the time-factor in evolution has been somewhat neglected in the past.[2]

In order to point out the possibilities for future work afforded by the application of geochronology to evolution, the chief results of the foregoing pages, and the conclusions to be drawn from them, are best summarized as follows.

Maximum rate of species evolution. (1) *There appears to be a fastest rate of evolution of species under natural conditions, namely about 500,000 years per species-step.*

Evidence shows that subspecific characters have appeared within a few thousand years. In other instances, forms have not passed the stage of subspecific differentiation after a few hundred thousand years. The fastest time-rate of species-evolution yet known is about 500,000 years.

Since many Recent species are able to interbreed, although the resulting offspring is usually sterile or of reduced fertility, one is inclined to think that several hundred thousand years have to pass before the change in chromosome-structure of a form assumes the proportions commonly found in related species. This period is rather longer than that available for genetic experiments on species-formation.

Number of generations and time. (2) *In evolution the number of generations appears to be less significant than the absolute time.*

One might argue that, for the reason given in the last paragraph, it will be advantageous to study groups in which the generations

[1] *Pleurotomaria* Defr., said to have persisted possibly since the Cambrian, probably since the Ordivician, may be regarded as an exception. But Wenz, in his recent revision of the Pleurotomariidae (1938), restricts the genus to forms from the Triassic to Recent.

[2] Notable exceptions are Haldane (for instance, 1932, pp. 144 ff.), and Huxley (1942). See also Note (10), p. 389.

follow one another very rapidly. It appears, however, that in nature the number of generations is not the only factor ruling the rate of change, and that absolute time enters the picture to some extent. In other words, the evolutionary step per generation may be proportionally greater in a form with a slow succession of generations than in a form with a rapid succession of generations.

At first sight this statement looks startling but, as I pointed out more than ten years ago (Zeuner, 1931*b*), evolution would on the whole proceed more rapidly for instance in certain Protozoa, Crustacea like *Daphnia* or *Cyclops*, aphids, or mice, than, for instance, in certain cicadas and wood-boring beetles (adult after 10 to 40 years of larval life), or elephants, if the rate of evolution in fact depended in the first instance on the number of generations. There is apparently no directly proportional relation between the rate of succession of generations and the rate of evolution, and genetic experiments based on this assumption may be based on a serious misconception. It is perhaps worth mentioning that a species of the genus *Drosophila* existed in the upper Eocene, about 45 to 50 million years ago.

It would indeed be difficult for a species with a rapid succession of generations to maintain its specific characters for any length of time if the rate of evolution depended on the number of generations. Short-timed climatic cycles of a few hundred years duration or, in exceptional cases like that of certain Protozoa which can produce generations every few hours, the sunspot cycle or even exceptional weather would cause a change in the characters of the species.

Species evolution beginning with a phase of great variability. (3) *Every species passes through an episode of rapid evolution but may become stabilized thereafter and persist unaltered for a long time.*

The observation that species have survived apparently unaltered for some 30 million years, whilst other species have evolved within half to one million years, strongly suggests that species pass through an initial phase of rapid evolution after which their characters become comparatively stable. Since the instances of rapid evolution of species were all taken from the Pleistocene (for lack of suitable material from earlier periods), it is difficult to offer conclusive proof of this contention. But indirect evidence is not entirely wanting.

An example is afforded by the Pleistocene elephants, particularly the mammoth, *Elephas primigenius*, which in its final stages had a very restricted range of variation in the lamellar structure of its molars, compared with the wide range of variation observed in its lower Pleistocene ancestor, *E. meridionalis nesti.*

For stretches of time longer than the Pleistocene, the same process of the reduction of the variability of specific characters is suggested by the different degree of consolidation found in the species of young and old genera. Recent genera in which plenty of variation,

individual or subspecific, is observed and in which the separation of the species is often difficult, are the following:

Equus (horses),	existing since the upper Pliocene
Bos (cattle),	,, ,, ,, upper Pliocene
Mus (mice),	,, ,, ,, Pliocene
Arvicola (voles),	,, ,, ,, lower Pleistocene
Canis (dogs and wolves),	,, ,, ,, upper Pliocene

None of these has been found in deposits older than the Pliocene.

On the other hand, the following Recent genera in which the species show little subspecific variation and in which the species (if more than one) are widely separated by constant differences, are known from earlier deposits:

Tapirus (tapirs),	existing since the upper Miocene
Dicerorhinus (Sumatran Rhino),	,, ,, ,, lower Miocene
Diceros (Black Rhino),	,, ,, ,, lower Pliocene
Capreolus (roe deer),	,, ,, ,, lower Pliocene
Hystrix (porcupine),	,, ,, ,, Oligocene

Instances of this kind tend to show that there is some justification in assuming that the species pass through an episode of intensified evolution while they are young, when their characters still have a greater range of variation. It appears that more subspecies are evolved by young species than by old ones.

(4) *Every higher category also passes through an episode of intense evolution, which lasts for something like 50 million years.*

This is the outcome of Part B (p. 352). It makes the process of evolution, viewed from the standpoint of time, appear somewhat 'jerky'. Some authors go further and call it discontinuous (Schindewolf, 1936, p. 85). The existence of an apparent minimum required for the formation of a new species, however, sets a limit to the suddenness of this process.

Limitations of explosive evolution. Now, this combination of our points (3) and (4) leads to an interesting conclusion. If genera pass through a period of abundant species-formation, lasting c. 50 million years, and if each species needs about one half to one million years to evolve, the number of successive species-steps in a lineage is limited to something of the order of 100 during the explosive episode of the genus, after which the rate slows down.

In spite of the vagueness of the figures here used it appears to me, therefore, that explosive evolution does not imply unlimited production of new forms, the number of species-steps in every affected lineage being limited to a comparatively small number.

Furthermore, the number of species-steps involved in the evolution of higher systematic categories is not larger than that involved in the evolution of lower categories.

Chronological aspect of evolution: quality, not quantity, is important. Clearly, if this picture deduced from chronology be true, the widely-

current conception that evolution proceeds evenly by means of innumerable steps, which is held by many geneticists as well as palaeontologists, cannot be strictly true. If it can be verified by other evidence that there are periods of a limited duration during which a stock evolves many diverse lineages at a rapid rate, the number of species-steps in each surviving lineage nevertheless remaining comparatively small, the conclusion is inevitable that the *quality* of the species-steps during the period of explosive evolution differs from those of the period of ordinary, non-explosive evolution.[1]

This view is supported by the results of two quite independent lines of research, namely by morphology, and by genetics.

Aromorphs. Sewertzoff (1931) who studied numerous lines of evolution, particularly of vertebrates, from the phylogenetic standpoint, came to the conclusion that it is necessary to distinguish evolutionary changes which result in an 'increase of the energy', or 'life-activity', of the form from ordinary changes which do not do so. The change in organization involved in the former case was called by him *aromorphosis*, hence it is convenient to call the resulting character an *aromorph*.

A few examples will make the difference clear.

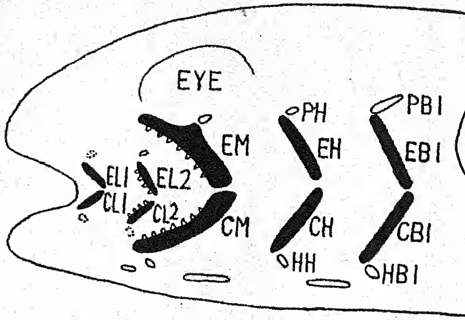
Jaws of vertebrates. One of the most important aromorphoses in the evolution of the Vertebrata was the conversion of one or several gill arches into the biting apparatus of the jaws (figs. 101–103; see Sewertzoff, 1931, or Romer, 1933). The most primitive fishes are jaw-less (Agnatha, extinct except for the modern lampreys and hag-fishes) and, therefore, restricted in the selection of their food. The appearance of jaws marked the beginning of the gnathostomous fishes; it enabled them 'to choose the food most suitable to them and to adapt themselves comparatively easily to it. Selection of the most suitable food, however, means better nourishment and, therefore, an increase in the general energy of life in these animals. The importance of a biting mouth-skeleton as weapon both offensive and defensive is obvious also.' (Translated from Sewertzoff, 1931, p. 75.)

If one compares this example of an aromorph with the evolution, for instance, of a highly specialized protective character, such as the leaf-shape of a leaf-insect (pl. XXII, fig. A), one realizes the difference between an aromorph and an ordinary adaptational character. The latter may be highly adapted to a certain manner of life, and be very useful, but it does not contribute to increasing the life-energy of the form. The aromorph, however, does so.

If one applies this conception to various classes, orders or families, one finds that very often there is one aromorph, or several, at the root of the line. Thus, there is the fold in the back of the throat

[1] These two periods are called *pre-adaptive phase* and *adaptive phase* respectively by Schindewolf (1936, p. 84).

FIG. 101



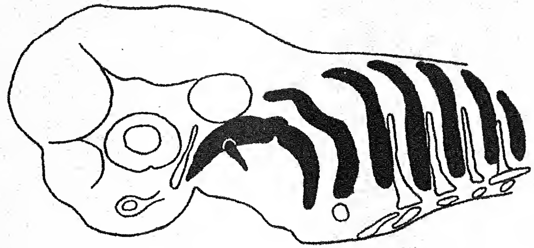


FIG. 102

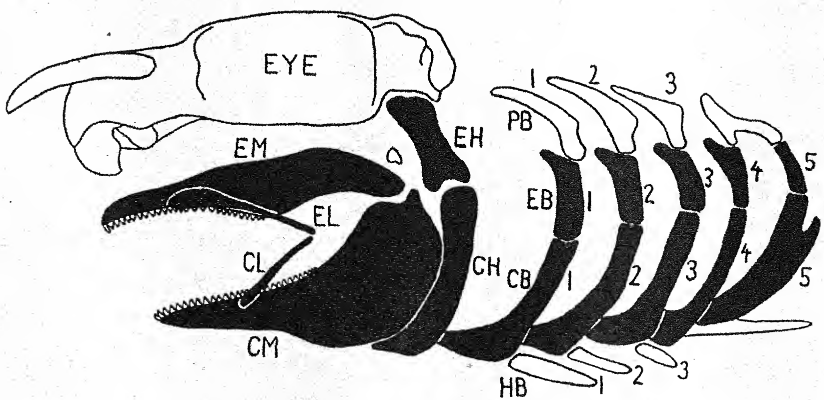


FIG. 103

FIGS. 101–3.—The aromorphosis of the anterior gill-arches in fishes: transformation of gill-arches into jaws.

FIG. 101.—Diagram of the elements of the branchial arches involved in the process.—After Sewertzoff (1931).

EL	Epilabiale	PH	Pharyngohyale	PB	Pharyngobranchiale
CL	Ceratolabiale	EH	Epihyale	EB	Epibranchiale
EM	Epimandibulare	CH	Ceratohyale	CB	Ceratobranchiale
CM	Ceratomandibulare	HH	Hypohyale	HB	Hypobranchiale

FIG. 102.—Embyro of dog-fish (*Scyliorhinus canicula*), showing the shift in position of the mandibular arch towards the mouth. Also illustrates the embryonic position of the head at right angles to the axis of the body.—Based on Parker (1878, pl. 34, fig. 1).

FIG. 103.—Skull of adult dog-fish, with anterior gill-arches transformed into jaws.—Based on Parker, W. K., 1878. On the structure and development of the skull in sharks and skates.—Trans. Zool. Soc. London, 10(4), pp. 189–234, pls. 34–42, (Pl. 38, fig. 2.)

of certain fishes, which was used for retaining air taken in by the mouth and which eventually became the lung of the amphibia and higher vertebrates (Romer, 1933, p. 70). There are the molar teeth of the mammalia which are used for masticating food. This mode of comminution of food before it reaches the digestive tract helps in extracting more energy ; it increases the life-energy of the animal. Warm-bloodedness and many other characters of the mammals are probably the consequence of a single important aromorph. The evolution of man also may be regarded as characterized by an aromorph, namely, erect posture (Note (1), p. 386).

These *qualitative* differences between aromorphs and ordinary adaptational characters appear to me to be one reason why evolution sometimes leads to the emergence of a new major group, and sometimes not (see also Note (2), p. 387). The time required for the evolution of an aromorph is, as has been shown in the earlier paragraphs of this chapter, *not* greater than that required for ordinary adaptations.

Conclusion. Inheritability of acquired characters and time. The attempt to consider organic evolution from a chronological point of view cannot be more than tentative. The reader may, and probably will, regard some of the views as highly conjectural, but it is open to him to test them with the material which he has at hand. In any case he will admit that with the establishment of geochronological time-scales a new element has entered into the study of evolution and that, as these time-scales are improved, they are bound to become increasingly valuable as measures of the actual rates of evolution.

The time rates of evolution, measured in years, are bound to play an important part in solving the old problem whether the mechanism studied by genetics, viz., chance-mutation and natural selection, is sufficient to explain evolution as a whole, or whether there is, after all, another mechanism which in the course of *long periods of time* renders inheritable features which were acquired during the lives of numerous successive generations in response to environment or habit. The latter alternative has been admitted as a possibility by several great Darwinists and geneticists, like Weismann (see Eimer, 1890, p. 174) and Haldane (1929, p. 31). It is the strongly held opinion of several great morphologists and anatomists, like Eimer in the past (1890, p. 807), and Wood Jones at the present time (1943, p. 99). In common with most palaeontologists, all these authorities agree that, if or when acquired characters become incorporated in the heritage of a species, it must be a matter of periods of time too long to be susceptible of experimental verification. For this reason alone it is well worth while to elaborate lineages from fossil evidence and to date the changes observed by means of geochronological time-scales. Evidence at

present available already suggests that the periods required for changes in specific characters are definitely beyond the reach of experiment.

I am confident that, ultimately, absolute chronology will attain the same significance in evolutionary research as now have dates and calendars in the study of human history. This, at any rate, is a goal worth working for.

APPENDIX

Note (1) (*p.* 384). *Aromorph in the evolution of Homo.*—The two most striking differences between man and ape are (*a*) the superior development of the brain in man, and (*b*) the completed change in man of the principal function of the fore-legs from locomotion to seizing and handling objects. In the monkeys and apes both changes are observed in an incipient state. At first sight they appear to be the result of two independent evolutionary trends, but they can be explained as the consequence of one primary change. Locomotion with the aid of the hind-legs only implies a modification of the vertebral column, which developed two concavities (*lordoses*) placing the centre of gravity above the pelvis and relieving the fore-legs entirely of their original function of locomotion. Compensating the erection of the body, the occipital foramen is placed on the underside of the skull in man, so that the direction of sight is at right angles to the direction of the vertebral column (*kyphosis* of the base of the skull). The inevitable consequence of this kyphosis is that space has become available for the development of a large brain. The great development of this organ in *Homo*, therefore, can be interpreted as the result of his erect posture. This has, I believe, first been suggested by Cunningham (1886) and elaborated by Weidenreich (1924).

Other workers consider the shape of the human skull, dependent on the large brain, as the primary feature which entails all others (Dabelow, 1931). The large brain is regarded as an embryonic character which, by gradual retardation of development, has been shifted into the adult stage (Theory of Foetalisation of Bolk; compare Schindewolf, 1931, p. 46; Haldane, 1932, p. 28, p. 149; detailed critical discussion in Weidenreich, 1941, p. 468). The view outlined in the preceding paragraph, however, is the more probable, since there is palaeontological evidence that 'erect posture' preceded the full development of the brain. Weidenreich (1940) who has studied the large material of *Homo erectus pekinensis* (Black) ('Sinanthropus', about 40 individuals) and of *Homo erectus erectus* (Dubois) ('Pithecanthropus', about six individuals), has been able to show that the leg-bones of these primitive men were already similar to those of modern *Homo sapiens*, whilst their skulls were still comparatively much more primitive. Erect posture, therefore, was perfected more rapidly than the enlargement of the braincase.

The chronology of the fossil remains of *Homo* has been discussed in earlier parts of this book, especially in Chapter IX, Part B. The evidence suggests that, broadly speaking, the more primitive forms dominate in the lower Pleistocene (*H. erectus-group*) and the advanced ones (*H. sapiens-group*) in the upper. To this extent, an advance towards a higher evolutionary level is recognizable.

If one considers individual finds, however, the evidence suggests that the lineage of *H. sapiens* goes back at least to the middle Pleistocene, if not even the lower Pleistocene, so that its divergence from the ancestral

stock of *Homo* appears to have begun earlier than is often supposed. Although the number of fossil specimens of *Homo* is smaller, it seems that we are here confronted with another instance of evolution of the type observed in the Pleistocene elephants of Europe.

In the lower Pleistocene, a primitive form of man dominates (*H. erectus*), but the future trend is heralded by a few specimens (none of which, incidentally, are regarded as accurately dated). In the middle Pleistocene, the trend towards *H. sapiens* is clearly established (though only two specimens known), and the *H. erectus-group* has disappeared. In the early upper Pleistocene, a type higher than *H. erectus*, but more primitive than *H. sapiens* and evidently of middle Pleistocene derivation, is frequent (*H. neanderthalensis*), whilst in the late upper Pleistocene the most advanced form (*H. sapiens*) becomes the only and universal representative of the stock. It is not impossible that *H. neanderthalensis* and *H. sapiens* evolved as ecological subspecies in a manner comparable with that of *E. trogontherii* and *E. antiquus*. If this picture can be substantiated by further evidence, it would appear that the evolution of *H. sapiens* from the ancestral hominids took place during the Pleistocene, with a fair chance that the initial stages date back to the late Pliocene. Roughly a million years, therefore, may be assigned to the evolution of *H. sapiens* as a species.

The aromorphosis of man in the wider sense was, of course, spread over a period longer than one million years. It is first indicated in the monkeys and has reached a somewhat higher level in the apes. The critical point was reached when the fore-legs ceased to be used for locomotion, and the genus *Homo* should, theoretically be reckoned as beginning at this stage. Since lower Pleistocene man had the erect posture in nearly the same perfection as Recent man, the critical point must have been reached earlier than this.

Note (2) (*p.* 384). *Qualitative differences in genetic mutations.*—It is remarkable that studies in genetics also have in recent years led to the conclusion that evolution does not proceed more or less evenly by innumerable small steps, but that there are qualitative differences in the mutations involved. This has been forcefully elaborated by Goldschmidt (1940), whose view may be stated partly in his own words (p. 199): 'Microevolution by means of micromutation leads only to diversification within the species' and 'The large step from species to species' (and from a higher category to another higher category) 'is neither demonstrated nor conceivable on the basis of accumulated micromutations.' The latter kind of step is called *systemic mutation* by Goldschmidt. It is improbable that this sharp differentiation between mutations producing subspecies and those producing species can be maintained, but it is at least evident that certain results of modern genetics support the view that *qualitative* differences mark the beginnings of new lines of evolution.

Note (3) (*p.* 258). *South African Chronology.*—Professor C. van Riet Lowe's paper, *The Evolution of the Levallois Technique in South Africa* (Man, London, 1945(37), pp. 49–59, pl. C), incorporates results obtained since 1937. Furthermore, he sent me a new climatogram to replace my fig. 77, but it arrived too late to be included. It extends the older climatogram into the past by adding phases for the Older Gravels. These are now called the *First Pluvial.* The Younger Gravels have

become the *Second Pluvial* (formerly First Wet Phase), and the Youngest Gravels and Schoolplaats Phase the *Third* and *Fourth Pluvials*. A final, minor, wet phase has been added. On the latest evidence, the position of the human industries is as follows : Late Older Gravels : Pre-Stellenbosch (pre-Abbevillian).—End of Older Gravels : Stellenbosch I (Clacto-Abbevillian).—End of interval between Older and Younger Gravels : Stellenbosch II (early Acheulian forms).—Younger Gravels I : Stellenbosch III (Proto-Levallois I plus middle Acheulian forms).—Younger Gravels II : Stellenbosch IV (Proto-Levallois II plus advanced Acheulian forms).—Younger Gravels III : Stellenbosch V (Levallois II plus Micoquian forms).—Youngest Gravels : Fauresmith I (Levallois III) and (near following interval) Fauresmith II (Levallois IV).—Schoolplaats phase : Middle Stone Age (Mousterio-Levallois, ' Solutrian ', early Aurignacian, &c.).—Final wet phase : Later Stone Age, Smithfield, Wilton, &c. (Capsio-Aurignacian, Tardenoisian, &c.).—I am very grateful to Professor van Riet Lowe for his permission to use this information.

Note (4) (*p.* 179). *Quaternary and Palaeolithic in Portugal.*—Consult also Breuil, H., and Zbyszewski, G., 1942. *Contribution à l'étude des industries paléolithiques du Portugal et de leurs rapports avec la géologie du Quaternaire.*—Com. Serv. geol. Portugal Lisboa, **23**, 369 pp., 74 pls.

Note (5) (*p.* 15). *Archaeological tree-ring dating in Norway.*—E. H. de Geer has further studied wood from an earthwork in Romerike in southern Norway (Geer, E. H. de, 1938. Raknehaugen.—Univ. Oldsaksamlings Årbook Oslo, 1937, pp. 27–54). Raknehaugen is an artificial hill 19 metres high and containing a large amount of timber. No burial has yet been found in it, but smaller barrows are mostly of Viking age, ninth to eleventh century. Four specimens of wood were obtained from Raknehaugen, the best providing a series of 66 years. The method of biennial maxima (amplified by ' triennial ' ones) was used in correlating this series with parts of the *Sequoia* curve from California, and of a varved-clay curve from Ångermanland, Sweden. E. H. de Geer finds the agreement satisfactory. But if one counts the cases of agreement and disagreement of the annual changes shown by the two tree-curves (her fig. 5), one finds 31 cases of agreement and 34 of disagreement. This is almost ideal chance distribution : in other words, the curves do *not* resemble each other. It should be noted, however, that the pine curve from Raknehaugen agrees somewhat better with the varved-clay curve from Sweden. The probability of this agreement being due to chance is about 1 in 20.—Although E. H. de Geer's attempts to introduce dendrochronology into Europe are to be welcomed, I cannot help feeling keptical with regard to the applicability of the Californian *Sequoia* curve to Europe's tree-growth. It would be more profitable first to build up a European tree-ring chronology of a more local character, from historic and prehistoric beams and other remains of wood, on the lines adopted by Douglass and his collaborators in Arizona, before the question of likeness of curves from different continents is raised.

Note (6) (*p.* 102). *The relative ages of archaeological objects recently found in bogs in Ireland.*—A valuable paper with this title, by G. F. Mitchell (Proc. R. Irish Acad., Dublin, (C) **50** (1), pp. 1–19, pl. 1) lists 23 finds, from Creswellian flint blades to Bronze Age tools, dated accord-

ing to pollen zones. It also gives a critical summary both of the pollen zones and of their archaeological contents in comparison with England.

Note (7) (*p.* 336). *Age of the Universe.*—An instructive article discussing the problems of the long and short time-scales is by Bok, J. Bart, 1936. *Galactic Dynamics and the Cosmic Time Scale.*—The Observatory, London, **59**, pp. 76–85. In *The Milky Way* (204 pp., Philadelphia, 1941), J. Bart and P. F. Bok derive, from galactic evidence, a maximum age of the order of 10,000 million years, whilst S. Chandrasekhar (*Galactic Evidences for the Time-scale of the Universe*, Science, **99**, pp. 133–6, 1944) finds that galactic clusters like the Pleiades suggest the order of 3,000 million years; binary stars, 5,000 million; and nebulae like the Virgo Cluster, according to Miss Tuberg's work, 100,000 million years. The order of a few thousand million years thus appears repeatedly, which leads to Bok's limitation, though Tuberg's result leaves open the possibility of a higher limit. McVittie (1944, *Models of the Universe and Cosmological Time-scales*,—Nature, London, **154**, pp. 477–81) discusses the mathematical models of the Universe designed by Eddington and by Milne. The former would have begun to expand about 90,000 million years ago (compare Tuberg's figure); the latter is of the order of 2,000 million years. But Milne has introduced the notion of two different time-scales, giving a physical interpretation also to a second time-co-ordinate, in terms of which the Universe may be regarded as equipped with an infinite life-time. J. B. S. Haldane (1944, *Radio-activity and the Origin of Life in Milne's Cosmology.*—Nature, London, **153**, p. 155) has pointed out that the acceptance of Milne's model would have remarkable biological consequences.—I am indebted to Professor A. C. Lane for several of the above references.

Note (8) (*p.* 273). *North-west India.*—Compare Nilsson, E., 1941. *Die Eiszeit in Indien.*—Geograf. Ann. Stockholm, 1941 (1–2), 23 pp.

Note (9) (*p.* 334). *Pleochroic Halos.*—For pleochroic halos, *A Quantitative Study of Pleochroic Halos*, by G. H. Henderson (Proc. R. Soc., London, (A) **145** (1934) and (A) **158** (1937)) should be consulted. Photographs will be found in Lane, A. C., 1937. *Measuring Geologic Time: Its Difficulties.*—Smithson. Rep. Washington, 1937, pp. 235–54, 2 pls., and in Kew-Lawson, D. E., 1927. *Pleochroic Halos in Biotite.*—Univ. Toronto Studies, (geol.) 24.

Note (10) (*p.* 378). *Evolution and Time.*—G. G. Simpson's recent book (*Tempo and Mode of Evolution.*—237 pp. Columbia U.P., 1944) discusses the time-factor. It is noteworthy that this author has independently found that there is no clear evidence for the supposedly more rapid evolution of lineages with shorter generations.

Note (11) (*p.* 233). *Nile Terraces.*—A study of the Nile terraces and the area west of Alexandria, based on literature, maps and discussions with local experts, and carried out jointly by Mr. Day Kimball and the present author, has shown that Sandford and Arkell's connection of terraces with sea-levels is more likely than Ball's, and that evidence for ancient shorelines from the Sicilian down to the Monastirian exists near Alexandria.

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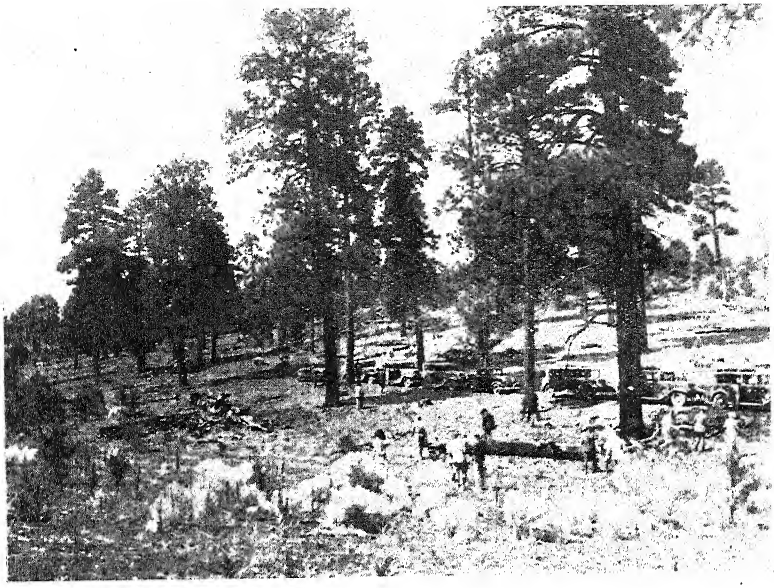
INDEX

NOTE.—For headings, and subjects discussed at some length, consult Contents, p. ix. For terms, geographical notations, genera and species, and authors' names, use Index. Most compound terms are indexed under the defining epithet ; exceptions are some important terms such as 'cycles' which recur frequently in different chapters and are treated from different angles. For dates, consult List of Chronological Tables, p. xvii.—Main reference in *italics*.

PLATES

Plate II.—*A.* Wood of ***Pinus ponderosa*** north-east of Flagstaff, Arizona, U.S.A. This pine has supplied most of the logs used in the construction of Indian pueblos, both prehistoric and historic. On it the tree-ring time-scale of Arizona depends.—Photo, M. S. Johnston.

B. Excavation of a prehistoric pit-house of the early Pueblo period, north-east of Flagstaff, Arizona. Note the remnants of poles in the ground. From these, sections are taken and the rings studied in the laboratory. The houses of this period were buried by volcanic ash from the eruption of the neighbouring Sunset Crater, about A.D. 800.—Photo, M. S. Johnston.

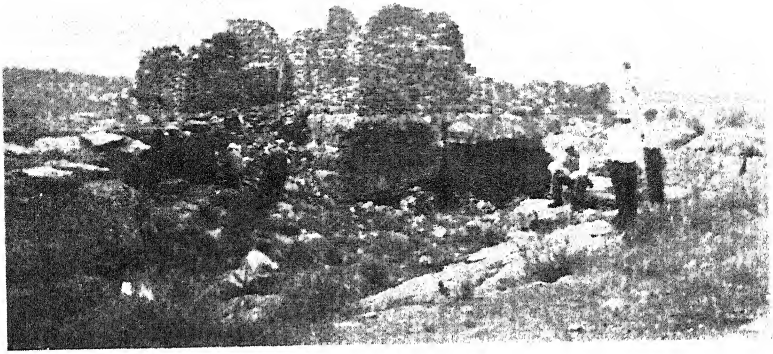


A

B

Plate III.—*A.* Wupatki, near Flagstaff, Arizona, a ruin of the Pueblo III period dating from about A.D. 1100. A masonry structure in which beams were used in the manner shown in fig. *B.*—Photo, M. S. Johnston.

B. Modern house (actually a garage) at Cameron Trading Post, Arizona, illustrating the use of wooden beams in the construction of pueblo houses. The ring-dates supplied by a number of these beams indicate the approximate time of the cutting of the trees and, therefore, of the building of the houses. As regards re-use of older beams, see p. 12.—Photo, M. S. Johnston.

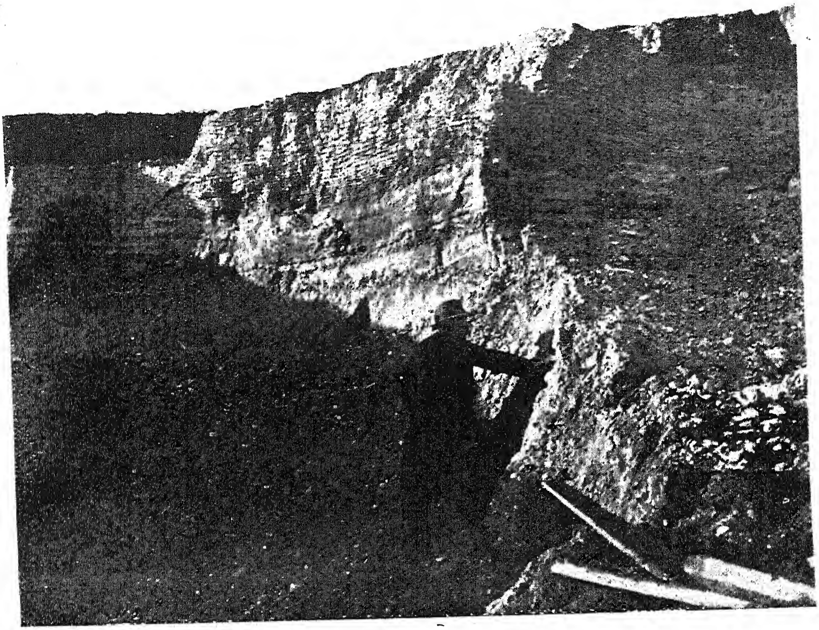


A

B

Plate IV.—*A.* A series of very coarse varves overlying, and developing from glacifluvial sands and gravels, at Opava, Sudeten Mountains, Czechoslovakia. Note the extraordinary thickness of the first six varves.—Photo, F. E. Zeuner.

B. A series of sandy varves overlying glacifluvial sands, at Sperenberg near Berlin, of the Brandenburgian phase of the Weichsel Glaciation.—Photo, F. E. Zeuner.



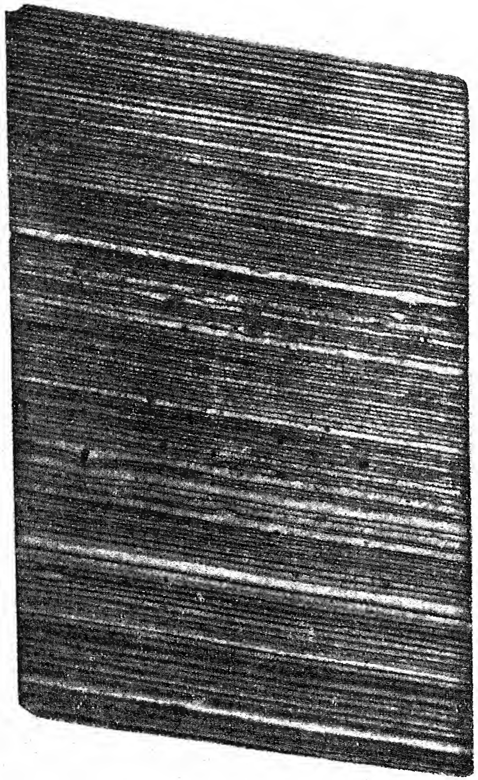
A

B

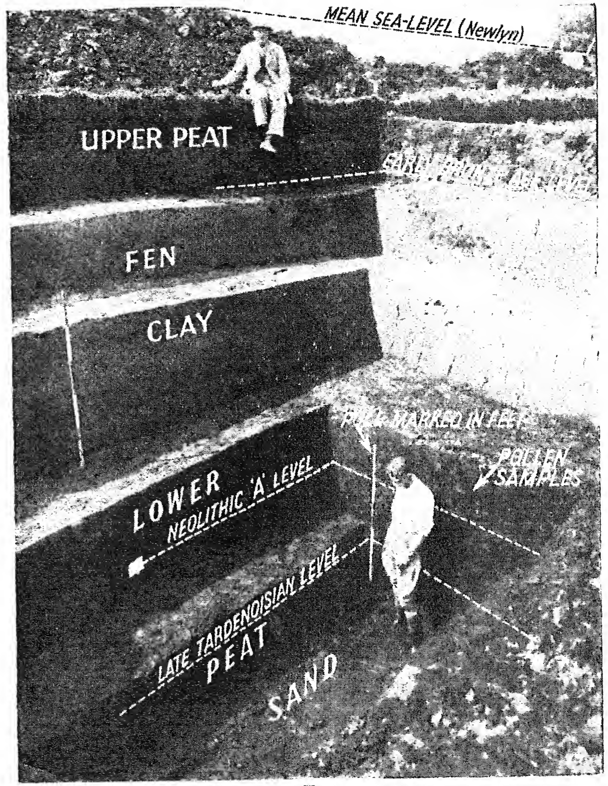
Plate V.—*A.* Late Palaeozoic varved clays from Faz, Pitanga, west of Limeira, State of São Paulo, Brazil. Polished section of a drill-core from a depth of 202 metres.—From Washburne, Bol. Comm. geogr. geol. São Paulo, no. 22, fig. 33 (1930), with permission.

B. The sequence of peat and fen-clay at Peacock's Farm, Cambridgeshire Fenland.—Photo, J. G. D. Clark.

PLATE V



A

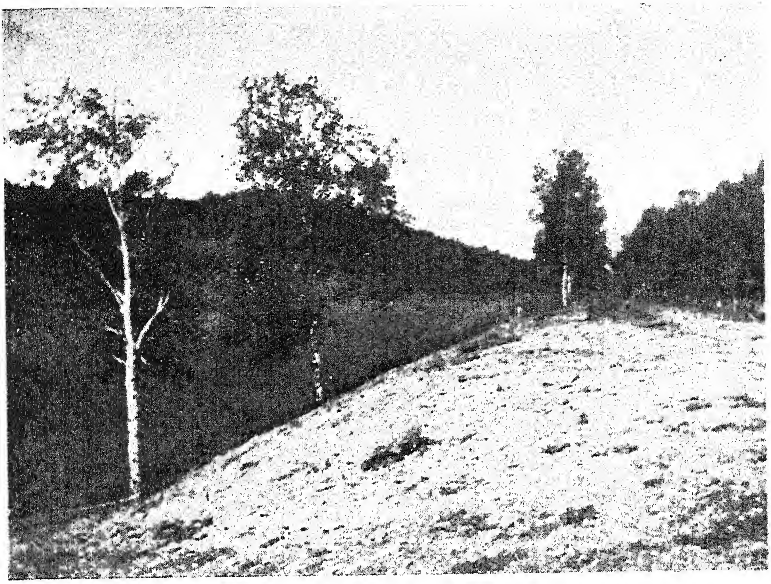


MEAN SEA-LEVEL (Newlyn)
UPPER PEAT
FEN
CLAY
MARKED IN FEET
POLLEN SAMPLES
LOWER
NEOLITHIC 'A' LEVEL
LATE TARDENOISIAN LEVEL
PEAT
SAND

B

Plate VI.—*A.* Spit-shaped shingle-beach of the Late Glacial Lake Algonquin, North America. West side of Gore Bay, Manitoulin Island of the present Lake Huron, Canada.—Photo, M. S. Johnston.

B. Two high beach levels of Postglacial age, east side of Gore Bay, Manitoulin Island, Lake Huron, Canada. The modern beach and the lake are seen in the distance.—Photo, M. S. Johnston.

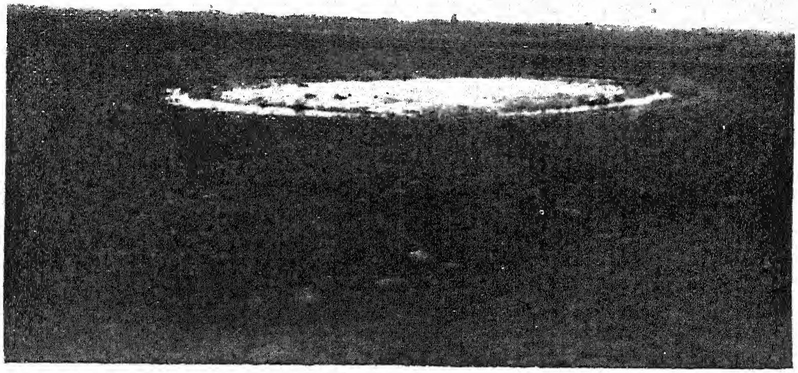


A

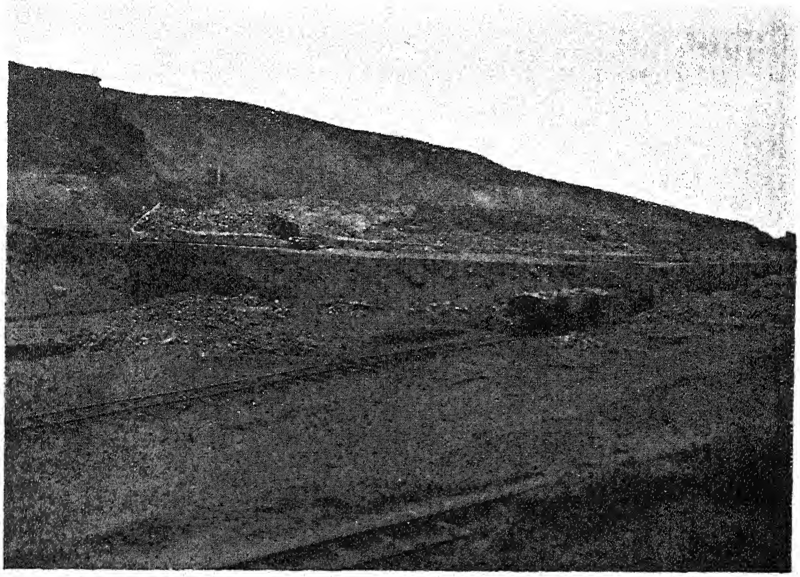
B

Plate VIII.—*A.* Bottom- or ground-moraine (boulder-clay) country of the Pomeranian Phase, in the foreground with an undrained hollow (' kettle hole '), probably formed by the thawing-out of a lump of dead-ice. Among other features, kettle-holes are evidence that the district was glaciated comparatively recently. North of the Great Baltic End-moraine near Eberswalde, north Germany.—Photo, F. E. Zeuner.

B. Section in the Great Baltic End-moraine of the Pomeranian Phase, showing sandy moraine and some boulder-clay (on left) containing enormous quantities of boulders (' erratics '). These are large enough to be quarried and shaped into pavement-stones, which are seen stacked up in the foreground on the right, and on the middle level of the pit on both sides of the screen. Joachimsthal, near Eberswalde, north Germany. Evidence of this kind plays a great part in the reconstruction of halts of the ice and, therefore, of the relative chronology, both in the Scandinavian and Alpine areas of glaciation.—Photo, F. E. Zeuner.



A



B

Plate IX.—A. ' Subglacial lake,' a water-channel formed below the ice and now occupied by a narrow lake. Area of the Great Baltic End-moraine, near Eberswalde, north Germany.—Photo, F. E. Zeuner.

B. Coarse, cross-bedded glacifluvial gravel, constituting the sandr of the Great Baltic End-moraine, near Eberswalde, north Germany.—Photo, F. E. Zeuner.

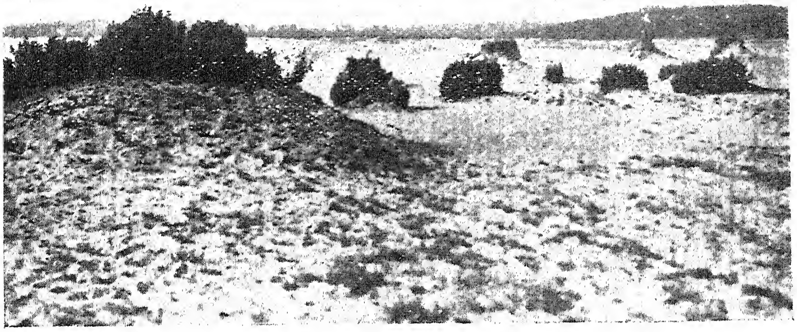
Plates VII, A, B, C : VIII, A, B ; and *IX, A*, illustrate 'fresh glacial surface-features' as observed in areas which have been ice-free for a relatively short time. Ground-moraine (Pl. *VIII, A*) lies to the north of a belt of hilly end-moraines (Pl. *VIII, B*) intersected by chains of lakes of subglacial origin (Pl. *IX, A*). The end-moraines pass southwards into sheets of glacifluvial gravels and sand (the 'sandr') which is coarse near the moraine (Pl. *IX, B*). The sandrs are often pitted with kettle-holes and intersected by chains of subglacial lakes in the same way as are the ground-moraine areas (Pl. *VIII, A*). They grade into one of the large valleys which carried the water both of the glaciers to the north and of the rivers coming from the south, westwards into the sea (see Pl. *X, A*, and Pl. *VII, C*, for an example from the Alpine area).

A

B

Plate X.—*A.* Dune sands in an *urstromtal*, at Złoty Potok near Częstochowa, Poland. The urstromtal probably dates from the Warthe Phase. Such 'dune fields' are not unfrequently found on the floors of the great glacifluvial drainage channels. From the shape of the larger dunes the direction of the prevailing wind at the time of their formation can be deduced. This particular field of inland-dunes is active at the present time. Most others have been fixed by vegetation at least since Atlantic times; they are of considerable archaeological interest since the relation of the sites to the dunes often gives a clue to their age. —Photo, F. E. Zeuner.

B. A 'dreikanter,' a quartzite boulder facetted by blown sand, on the surface of a sandr stratum at Kamenz, middle Silesia. Evidence of intense wind action during the glacial phases. Much of the loess is dust blown from the sandr belt into the steppe zone of the periglacial area (see Pl. *XII*, *B*).—Photo, F. E. Zeuner.

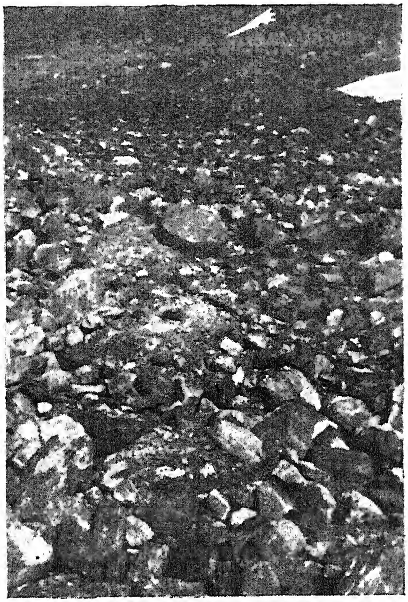


A

B

Plate XI.—*A.* Three stone-rings or brodel-centres in coarse morainic debris. Klostertal Glacier, Silvretta, Austrian Alps, about 7,400 ft. above sea-level. A measure, 8 inches long, lies on the second ring. Brodel phenomena are caused by regularly repeated freezing and thawing and are typical of snow climates. In the fossil state, they have provided most important evidence for the character of the glacial climate.—Photo, F. E. Zeuner.

B. Klostertal Glacier and morainic area in which stone-rings occur. Locality, see *A.*—Photo, F. E. Zeuner.



A

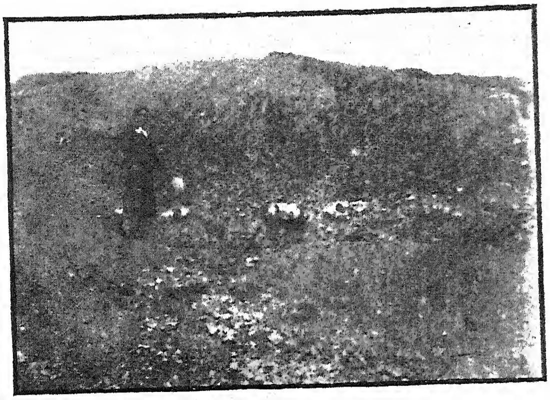
B

Plate XII.—*A.* Section in a structured frost-soil on Chalk, with separation of coarse constituents at the bottom and in pillars reaching upwards, and of fine material in the centres. Probably a brodel soil, usually called *trail*. Evidence for frost climate during the glacial phases. Thetford, Norfolk, England.—Photo, F. E. Zeuner.

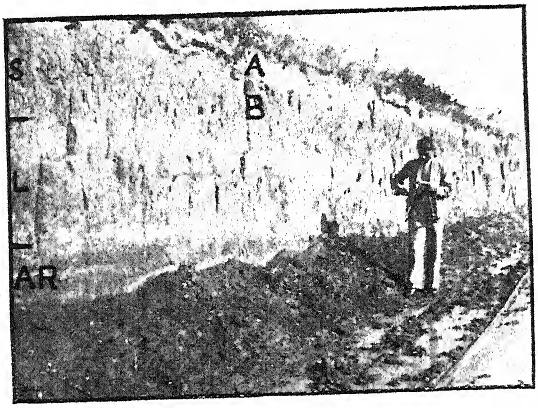
B. Loess-section of Fitz-James, near Clermont, Oise, north France. Note the vertical cleavage typical of loess in the unweathered portion. The weathering profile exhibits the A- and B-horizons ; it is a slightly podsolized forest-soil.

S : soil.—L : fresh Younger Loess, so-called C-horizon of the soil.—AR : Argile rouge, a fossil, semi-mediterranean soil of the Last Interglacial, resting on Older Loess.—Photo, F. E. Zeuner.

C. Gravel (G) of the 30 metre-terrace at Cagny, near Amiens, north France, with Lower to early Middle Acheulian, of Penultimate Interglacial age, covered by a solifluction horizon (S) and by Older Loess, the last two from the Penultimate Glaciation. Illustrating the change of climate from temperate (interglacial gravels) to cold and wet (solifluction) and finally to cold and dry (loess) of a glacial phase.—Photo, F. E. Zeuner.



A



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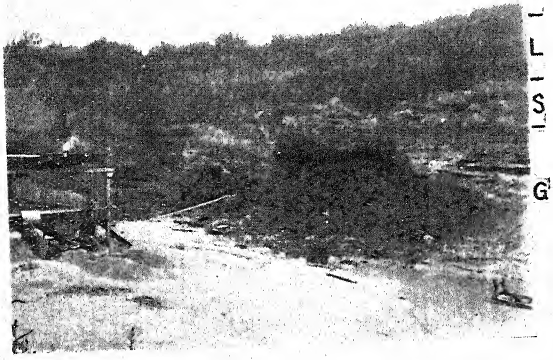
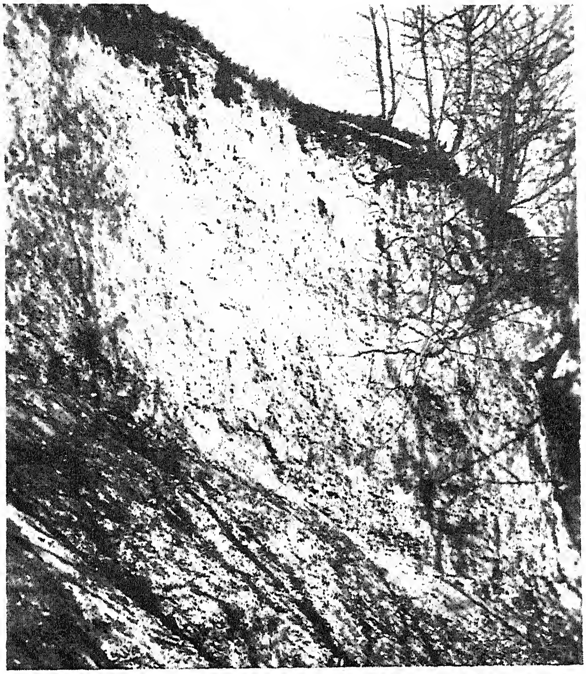


C

Plate XIII.—*A.* River gravel passing upwards into sand and loam, as the aggradation came to an end. Example of a climatically aggraded river deposit, beginning during an interglacial and ending with the loess phase of the following glacial phase. Terrace of the first phase of the Last Glaciation, between Dürrhartha and Kamenz, middle Silesia.—Photo, F. E. Zeuner.

B. Miniature example of a river aggrading under 'periglacial' conditions, with load exceeding water supply, and with scanty and interrupted vegetation of the country. This is actually a stream formed in ballast pits at Przeslebie, upper Silesia, and not more than 5 to 10 yards wide.—Photo, F. E. Zeuner.



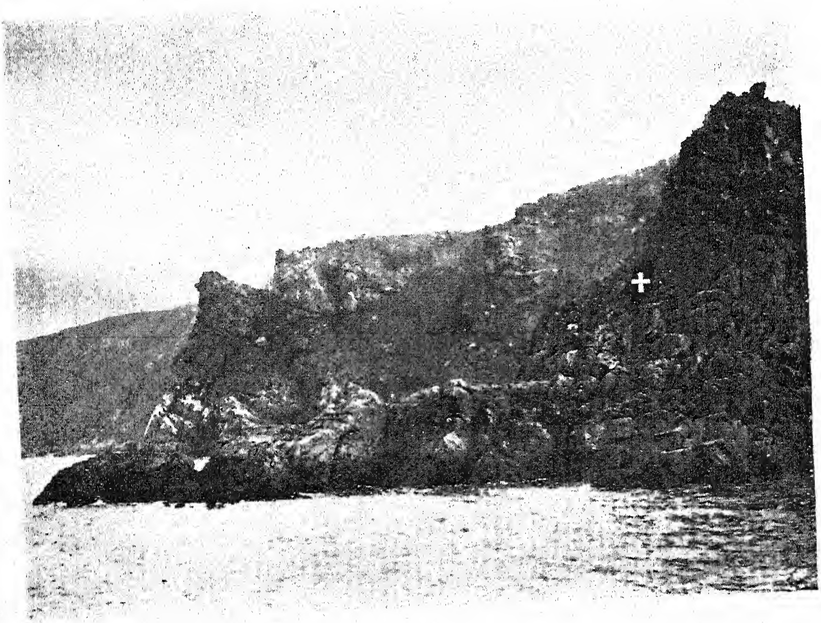
A

B

Plate XIV.—*A*. The undercut or notch, and part of the platform of abrasion, of the Late Monastirian (Late Last Interglacial) sea-level, at Les Rouaux, north coast of Jersey, Channel Islands. Sediments which covered the platform have been removed by the sea. The notch is a most important indicator of high-water mark. This type of evidence (see also *B*, and Pl. *XV*, *A*, *B*) is used in determining the exact height of interglacial sea-levels ; it is important for the world-wide correlation both of Pleistocene phases and the stages of the Palaeolithic.—Photo, A. E. Mourant.

B. The Cotte à la Chèvre (white cross), north coast of Jersey, Channel Islands. Cave formed during the Main Monastirian phase (60-foot sea-level), followed by occupation by Middle-Upper Levalloisian man. In the foreground the platform of the 25-foot sea-level of the Late Monastirian. Both Monastirian levels are Last Interglacial.—Photo, E. F. Guiton.

A

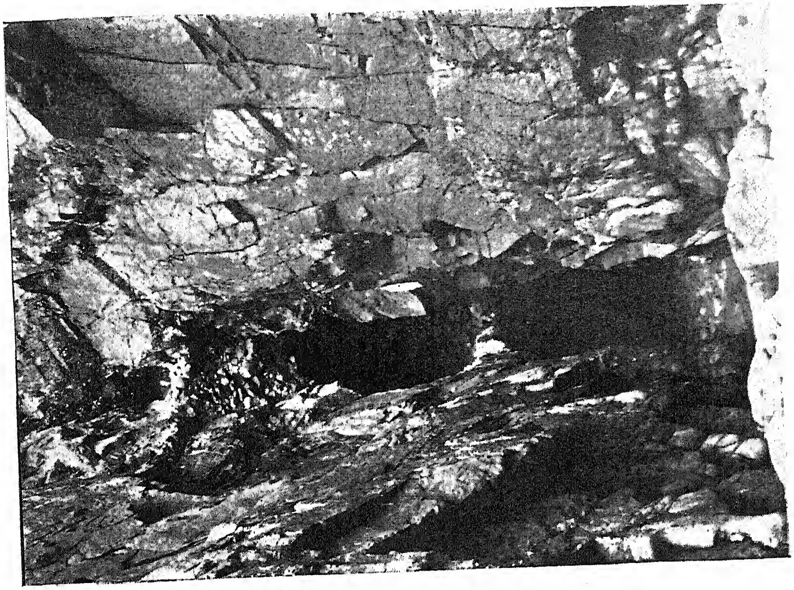


B

Plate XV.—*A.* The gulley separating Isle Agois from the main isle of Jersey, Channel Islands, during low-water. In the gulley, the notches of the Main Monastirian (60 ft.) and Late Monastirian (25 ft.) levels are marked. There are no fewer than three Recent notches in close succession, the origin of which is not clear.—Photo, E. F. Guiton.

B. The Creux Gabourel, north coast of Jersey, Channel Islands, during low-water. In a fissure carved into the granite along a soft basic dyke, the 25-foot beach (Late Monastirian) conglomerate is found in a suspended position. Since its deposition the soft rock underneath has been removed by further wave-action. The upper cave is entirely in the solidified beach-conglomerate.—Photo, E. F. Guiton.

PLATE XV



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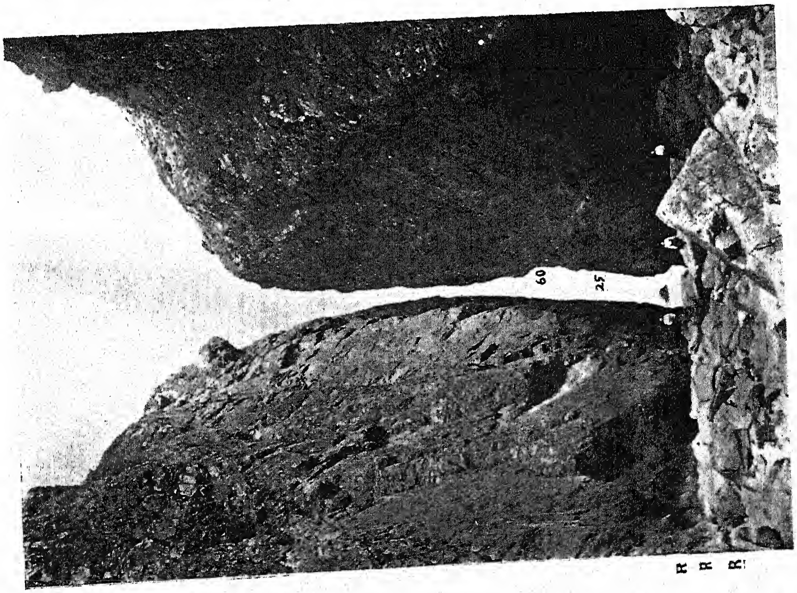
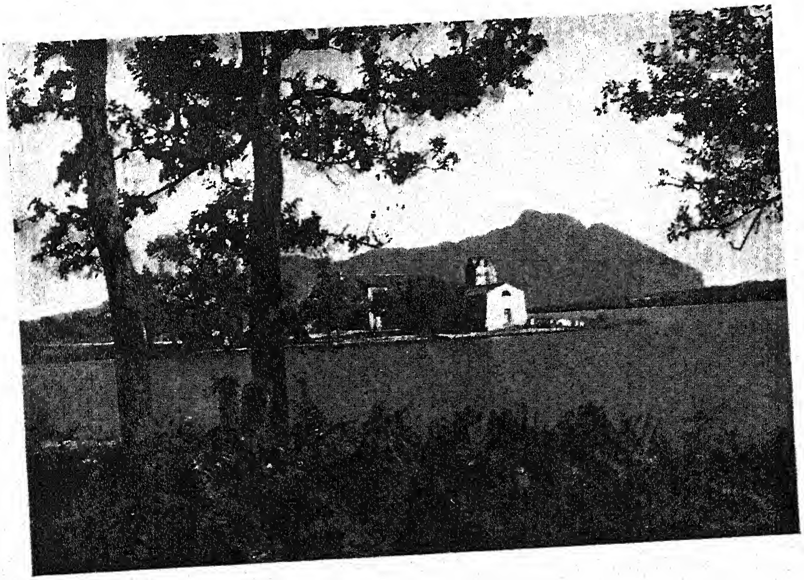


A

Plate XVI.—*A.* View of the Lower Versilia, northern Italy, towards the north. Town of Viareggio in the foreground, Apuan Alps in the distance. This plain, several miles wide, consists of late Pleistocene deposits at least 300 feet thick. The town stands on the flat modern beachbar, the marshes behind consist of peat. In the succession of deposits, Mousterian and Aurignacian have been found.—From a postcard.

B. Lago di Paolo, Pontine Marshes, middle Italy. Standing on the 'red dune' containing Mousterian and Aurignacian, one looks across the lake towards the Monte Circeo, famous for its many Palaeolithic caves. Between the foreground and the chapel (S. Maria della Sorresca), a branch of the lake runs inland; this is one of the drowned river valleys. Between the chapel and the flat ridge in the distance on the right, the main lake is seen. It runs parallel to the sea from which it is separated by the ridge, i.e. the 'white dune'. The white dune runs in a curve towards the right-hand end of Monte Circeo; it is the beach bar formed since the third phase of the Last Glaciation. The drowned river valleys were active during the phase of low sea-level of the third phase of the Last Glaciation, and the red dune, therefore, is at least as old as the preceding interstadial ($LGI_{2/3}$). This illustrates how industries can be dated relative to phases of sea-level.—From a postcard.

A

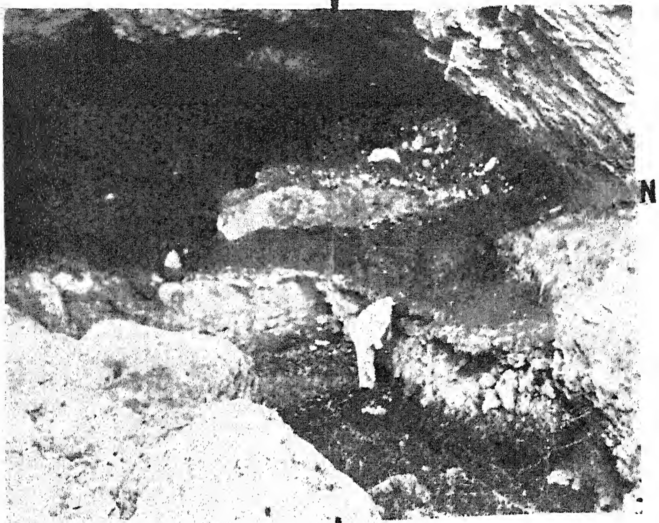


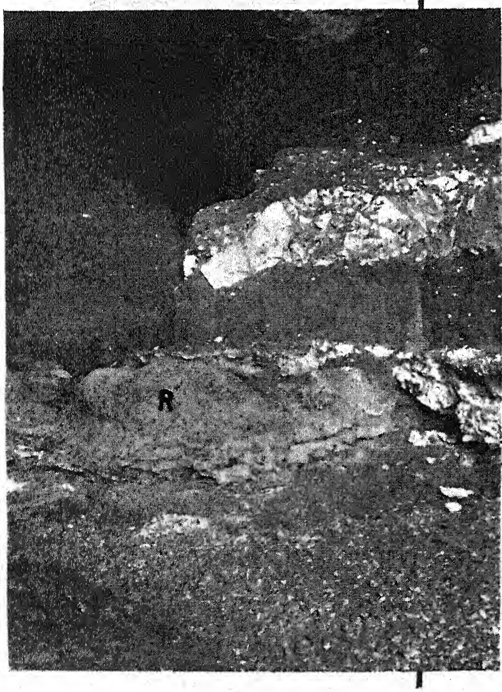
B

Plate XVII.—*A*. Grotta Romanelli, Apulia, southern Italy. From the entrance into the interior. In the foreground a channel cut into the rock by the sea. N : notch of the Late Monastirian sea-level formed previous to the filling of the cave.—Photo, F. E. Zeuner.

B. Detail of *A*, at the corner in the section marked by the vertical line. Strata lettered as in text, p. 223. Aurignacian of the Grimaldian variety in A to E, and G. R : solid rock.—Photo, F. E. Zeuner.

A





A
to Terra
E Bruna

Blocks with F behind

G Terra Rossa.

H Low Stalagmite.

I

K Beach pebbles.

B

Plate XVIII.—*A.* Older Gravels of the River Vaal at Vereeniging, Transvaal, South Africa. 50-foot terrace, antedating the so-called First Wet Phase, with pre-Stellenbosch pebble industry and with Stellenbosch I. The Abbé Breuil picking up implements.—Photo, C. van Riet Lowe.

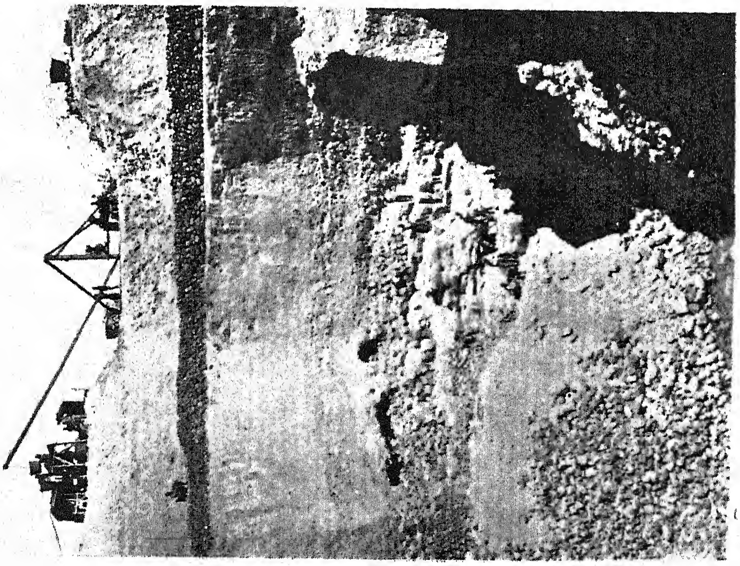
B. Riverview Estates, Windsorton, Cape of Good Hope, South Africa. 80- to 100-foot 'Older Gravel' terrace of Amandelhoogte marked with cross. Photograph taken from the 25-foot Younger Gravels terrace looking downstream River Vaal. The boulders in the foreground were extracted from the 25-foot terrace.—Photo, C. van Riet Lowe.

A

B

Plate XIX.—*A.* Excavation into the 35-foot terrace of the Vaal River (Younger Gravels, First Wet Phase) on the property Riverview Estates opposite Windsorton, Cape of Good Hope. Site II of Söhnge, Visser and van Riet Lowe, 1937, plate I. Gravel resting on irregular rock floor, and followed by sands. Pre-Stellenbosch and Stellenbosch I–III rolled in the gravel, Stellenbosch IV unrolled in the gravel, and Stellenbosch V in the sand (rare). *Hipparion* found in the gravel.—Photo, and details of explanation, C. van Riet Lowe.

B. Typical Younger Gravels II in the 25-foot terrace of the Vaal at Riverview Estates, Windsorton, Cape of Good Hope. The Abbé Breuil indicating a Stellenbosch III core of Proto-Levallois I form, which is slightly rolled and, therefore, derived. Gravel at this point about 14 feet deep and overlain by a similar depth of calcified sand. Note the size of the boulders. Implements and fossils occur in all levels of these gravels.—Photo, and details of explanation, C. van Riet Lowe.

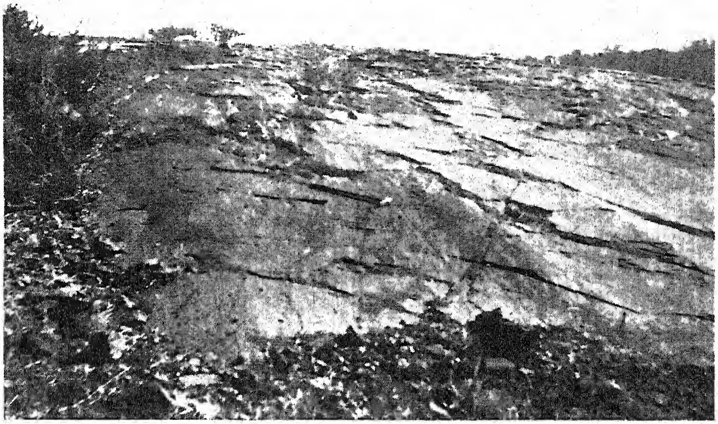


A

B

Plate XX.—*A.* Smoothed and striated rock-floor exposed beneath Dwyka Tillite, a hardened boulder-clay of Permo-Carboniferous age, at Nooitgedacht, near Riverton, Barkly West district, South Africa. Evidence for a Palaeozoic glaciation. Varved shales also have been found in this area.—Photo, M. S. Johnston.

B. A dolerite dyke of Karroo type in Beaufort Sandstone (Triassic), north of Beaufort West, Cape of Good Hope, South Africa. The dyke traverses the sandstone at right angles to the strata. In the photograph it extends from the foreground to the top of the hill. In the distance is seen a sill, intruded into a bedding plane of the sandstone, crossing the dyke.—Photo, M. S. Johnston.

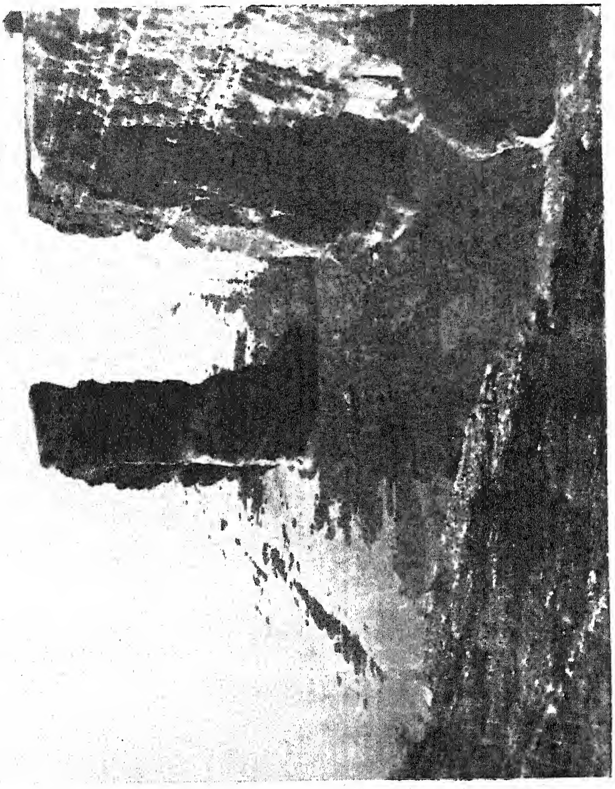


A

B

Plate XXI.—*A*. Horizon of beach pebbles of the Late Monastirian (25 ft.) sea-level resting on loess-like loam and covered by slightly stratified loessic 'head' (a solifluction deposit), at Portelet Bay, south coast of Jersey, Channel Islands.—Photo, F. E. Zeuner.

B. Cliff, undercut and platform of abrasion at Heligoland, North Sea. The undercut is, at this spot, distinct only at the base of the cliff on the right. About half-tide, or mean-sea-level. The platform is normally covered at high-water which, subject to the usual fluctuations, reaches the undercut. This cliff is being cut back at the rate of about three feet per year.—Photo, F. E. Zeuner.



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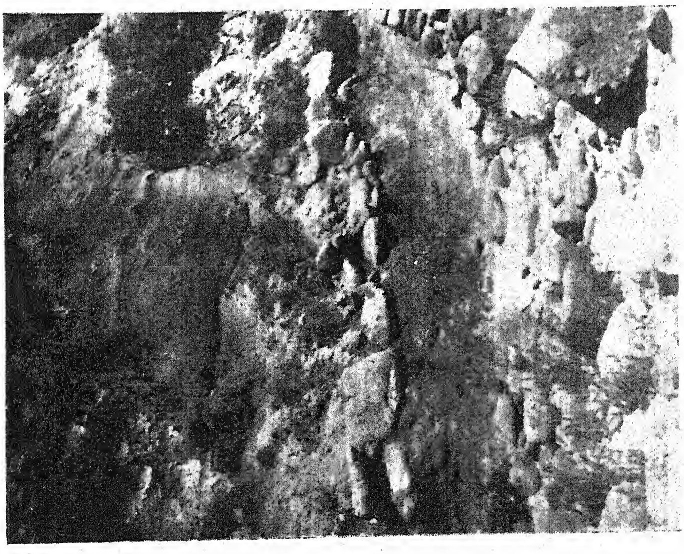
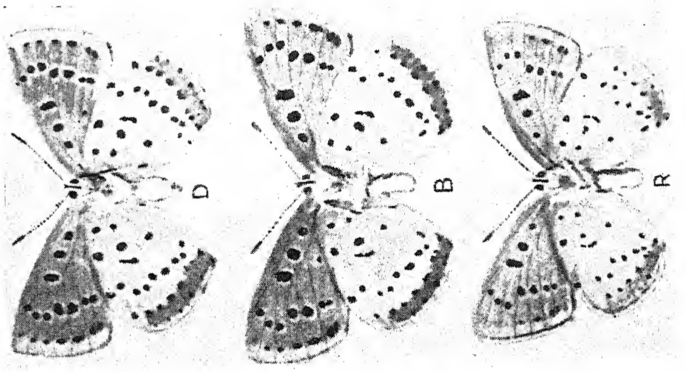


A

Plate XXII.—*A. Pulchriphyllium crurifolium* Serv., a leaf-imitating insect of the order Phasmodea. Illustrating an extreme case of adaption without aromorphosis (p. 381).—Reproduced with permission of the Trustees of the British Museum (Natural History).

B. The undersides of females of the three west European races of *Lycaena dispar.* 'D' British race (*L. dispar dispar*); 'B' Dutch race (*L. dispar batavus*); 'R' Continental race (*L. dispar rutilus*). Note the great difference of R from either B or D. Time of separation of D from R about 15,000 years, of D from B about 7,500 years.—Reproduced with permission of the Royal Entomological Society, London.



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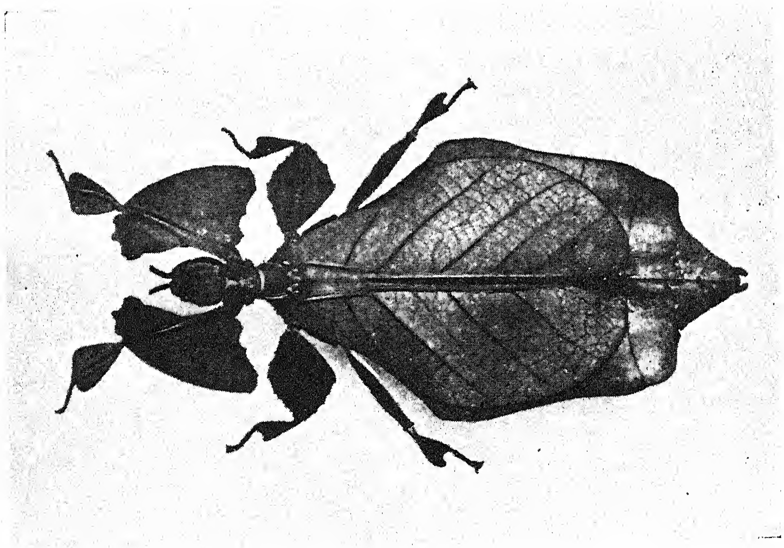


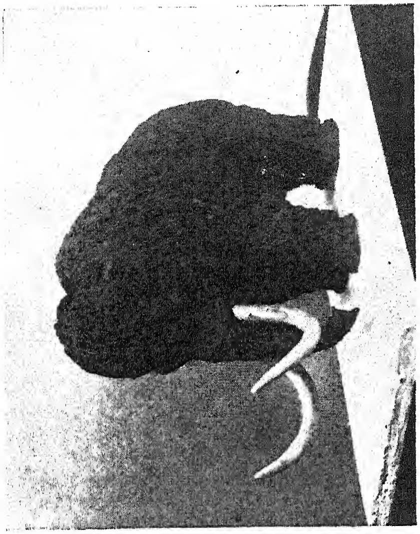
A

Plate XXIII.—*A. Elephas meridionalis* Nesti, late Pliocene and early Pleistocene.

B. Elephas antiquus Falc., Pleistocene forest elephant of Europe.

C. Elephas primigenius Blum., upper Pleistocene steppe elephant of Europe.

The last two are descendants of the first, and the process of differentiation of the two younger species required about half a million years. Reconstructions by the author, made for the British Museum (Natural History).



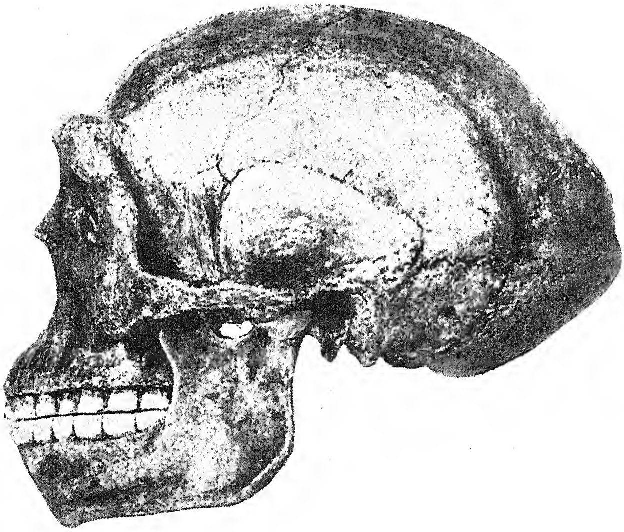
C

B

A

Plate XXIV.—*A.* Reconstruction of a female skull of *Homo erectus pekinensis* (Black), based on Sinanthropus Skull XI, facial bones No. I–III, and Mandible H1. Reconstructed by F. Weidenreich, reproduced from Weidenreich (1943, pl. 35, fig. 86), with the author's permission.

B. Detailed view of the Neanderthal skull from Grotta Guattari, Monte Circeo.—Photo, A. C. Blanc.



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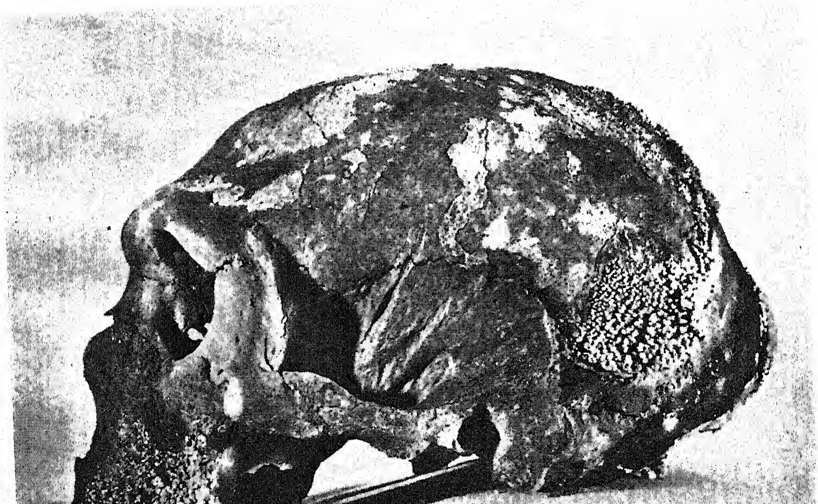

B